ECONOMIC GEOLOGY

Vol. XXI. SEPTEMBER, 1926. No. 6

SUCCESSIVE BANDING AROUND ROCK FRAGMENTS IN VEINS.*

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THE texture of many mineral veins is homogeneous, indicating simultaneous crystallization. Some of these have formed by replacement, some by infilling into fissures. Both classes may contain portions of the wall rock. In the replacement vein these are residua of replacement; in the infilled or fissure veins and vein-dikes they are fragments which have become involved in the ore solution when it was so dense that these fragments could be supported.

From the type of fissure veins which show homogeneous crystallization, there is a gradation to veins which show more or less distinctly a progressive crystallization, resulting in a faint or clear banding growing out from the walls. This structure is not an evidence of deposition by waters coursing through a fissure; it is equally compatible with deposition from a highly concentrated ore-solution standing quietly in a fissure and crystallizing leisurely.

In such banded veins we find in many cases suspended angular fragments of the wall rock; and we may find these fragments surrounded by the same successive rings of deposition as those deposited on the walls. Such a structure is not only compatible with crystallization from a dense static ore-solution, but affords a better proof of this origin than the homogeneous veins, since the first ring around the isolated fragments defines their shapes

* Read at the New York meeting of the Society of Economic Geologists, May, 1925.

at the beginning of crystallization. The suspicion that these fragments may be residua of replacement is thus excluded.

As an example, I have studied fragments of a vein sent to me from the Alacrán mines, in Zacualpan, Mexico. I have to thank Mr. Paul X. Stoffel for sending me the original specimen and calling attention to the structure, and Señor Ing. Luis C. Espinosa, mining geologist and engineer of the Mexico City, who has supplied me with descriptions and additional material. The ores

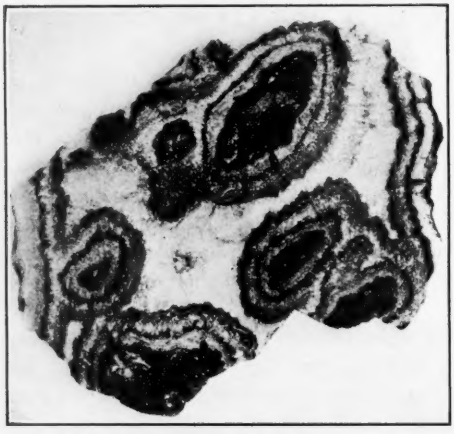

FIG. 1. Photograph of specimen of "orbicular" vein. Alacrán mine, Zacualpan, Mexico. Width of specimen 6 inches.

of these mines are silver ores, carrying the rich silver sulphides, sulpharsenides, and sulphantimonides: these minerals are ordinarily associated with sulphides of lead, zinc, copper, and iron. There is some gold.

The veins are described by Mr. Espinosa as "true fissure veins," with a principally quartz gangue, in altered sedimentary rocks much metamorphosed by intrusives. In width they vary from a centimeter to a meter and a half. The veins are typically banded. In certain extensive zones the bands are parallel and

symmetrical to the walls; in other zones, the veins contain included fragments, around which is concentric banding, so that the veins have been aptly called "orbicular veins."

Figure 1 is a photograph of a specimen of an orbicular vein, showing apparently the entire width of the vein, 6 in. I have thought it worth while to draw accurately the successive stages of crystallization, in order to follow the history. The inclusions are of slaty or altered shaly rock, very likely a tuff; and the slaty lamination is oriented differently in different fragments, and differs as between the fragments and the walls, which are of the

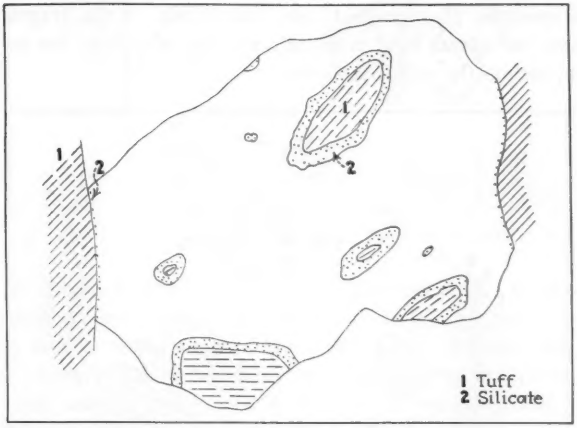

FIG. 2. Analysis of Fig. 1, showing first stage of deposition in vein.

same rock. This of course proves by itself that the fragments are not residua of replacement, even though they are rounded, rather than angular. Also, these fragments contain veinlets of an older barren ("bull") quartz, antedating the opening of the fissures; and the successive bands to be presently described build upon the broken edges of this quartz.

The first deposit on the fragments was a brown mineral (2, Fig. 2). The hand lens shows a sharp contact between this and

the slaty fragments (1, Fig. 2). The band is usually over a tenth of an inch in thickness around the fragments; but it occurs on the walls only as a thin skin, although all the subsequent rings are about equally thick on the walls and around the fragments. This brown mineral has been determined by Prof. J. Volney Lewis as a hydrous silicate of lime, ferric iron, and manganese, apparently a new mineral. I take it that this silicate, like most silicates, represents a relatively high temperature in the ore solution; also, that its failure to deposit on the walls indicates that the fragments migrated in the magma to their present position after the silicate deposition. Moreover, on the obverse side of the specimen photographed, one side of one of the fragments shows the silicate band practically missing, with only the barest film, such as the wall rock shows.

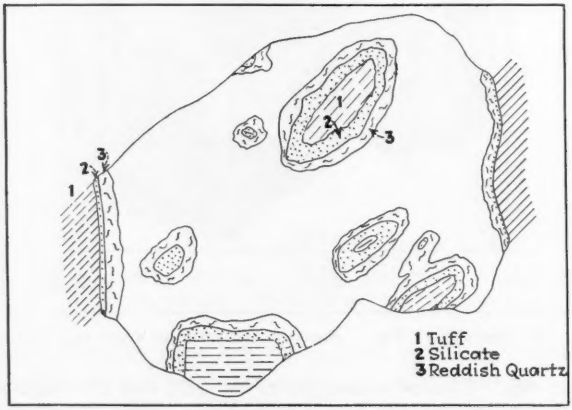

FIG. 3. Analysis of Fig. 1, showing second stage of deposition in vein.

Next came a band of reddish quartz (3), which formed with equal thickness around the fragments and on the walls, with a thickness of about 3/20 to 5/20 inch (Fig. 3). This quartz cemented together a larger fragment and a smaller one in the lower right-hand part of the drawing.

Next came the deposition of a black band of silver sulphides (4), deposited uniformly around floating fragments and on walls. This had a thickness of about 1/20 of an inch (Fig. 4).

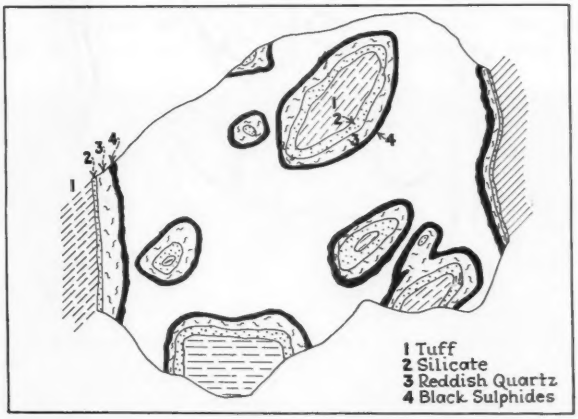

FIG. 4. Analysis of Fig. 1, showing third stage of deposition in vein.

Next came a band of gray quartz (5) on walls and fragments alike, and about 3/20 of an inch thick. This deposition for the first time cemented some of the fragments to the wall rock; it also cemented pairs of neighboring fragments together (Fig. 5).

Next came a pyrite band some 2/20 of an inch thick (6), which reduced still further the open space (Fig. 6).

The remaining space was now filled with white quartz (7) which grew out in long crystals from the nodules shown in Fig. 6, into the open spaces, resulting in comb structure. This, together with the other phenomena, shows a gradual deposition from the walls and fragments outward. Not only is the origin of the fragments by replacement excluded, but also the origin of the banding by Liesegang's rings, which are successive contemporaneous rhythmic bands which have been formed experimentally in gels. The bands in the Zacualpan vein were not contempo-

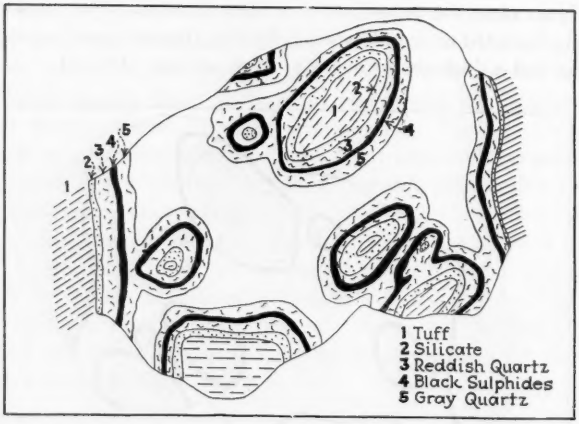

FIG. 5. Analysis of Fig. 1, showing fourth stage of deposition in vein.

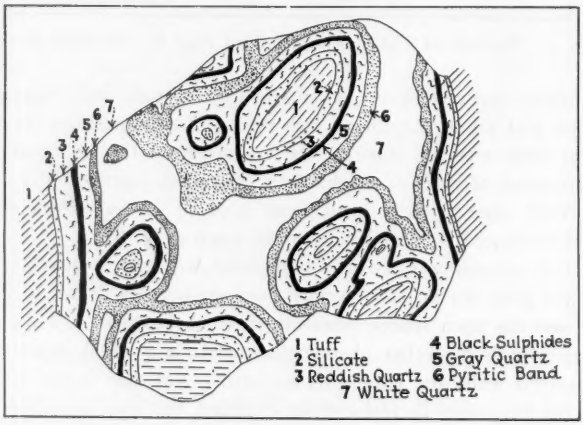

FIG. 6. Analysis of Fig. 1, showing fifth and sixth (last) stage of deposition in vein.

raneous, but represent six successive precipitations out of a solution. These precipitations, to recapitulate, were: silicate (lime-iron-manganese); silica; silver sulphides; silica; pyrite; silica: this suggests a rhythmic precipitation out of a single solution, with falling temperature. But this solution must have been able to float the fragments, for they were clearly separated from one

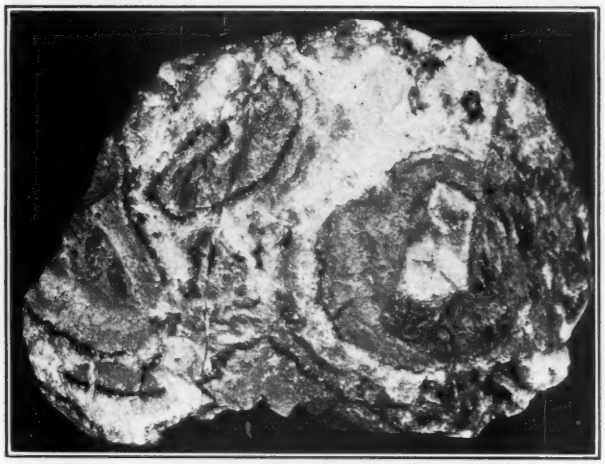

FIG. 7. Photograph of second specimen of "orbicular" vein, Alacrán mine, Zacualpan, Mexico. Width of specimen about 6 inches.

another and from the wall rock at first, and only became connected through the growth of deposition bands; it must therefore either have been so highly concentrated that it had a higher specific gravity than the specimens, or (which other instances render far more likely) the solution was in a physical condition which gave it supporting power.

Another specimen from the same vein shows interesting variations. Photographs of the two sides of this are shown in Figs. 7 and 8; explanatory drawings in Figs. 9 and 10. The first brown silicate stage (2) is far more abundant than in the first

FIG. 8. Converse side of same specimen as Fig. 7.

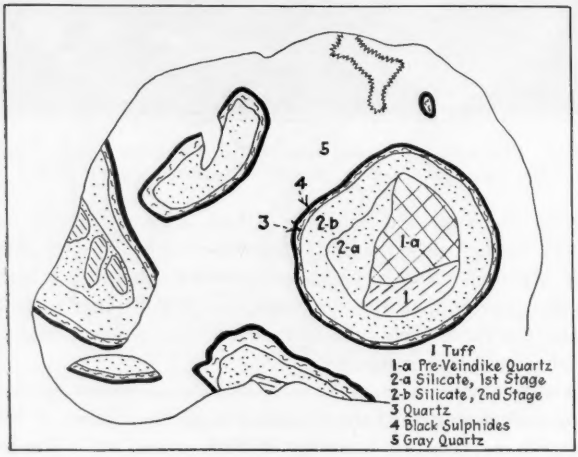

FIG. 9. Analytical drawing of Fig. 7.

specimen (Fig. 1), and is divisible into two successive stages—an apparently amorphous stage (*2–A*) and a later clearly fibrous and banded stage (*2–B*). (See Fig. 9.) There is in this second specimen clearer evidence than in the first that even *2–A* was not formed by replacement, for it builds upon the earlier bull quartz (*1–a*) in the slaty fragments (1), and contains slivers of slate

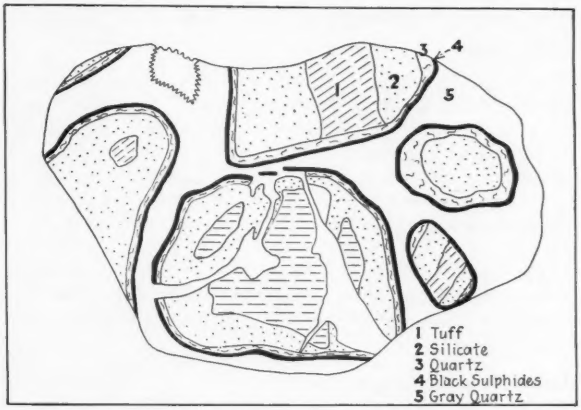

FIG. 10. Analytical drawing of Fig. 8.

differently oriented. There was, moreover, movement and some spalling off of the fragments between *2–a* and *2–b*, shown in some cases (Fig. 9). This process continued after the *2–b* deposition, as is clearly shown in some fragments (Fig. 10). Moreover, further spalling took place after the deposition of the quartz band 3, so that the sulphide band 4 was locally deposited directly upon the slate surface (Fig. 10). Again, this spalling process continued after the deposition of 4, as is strikingly shown in more than one instance (Fig. 10). The subsequent quartz band 5 completed the cementation of the open spaces in this specimen: hence, 6 and 7 are not represented, this final ore-magma fraction having been drawn off into the still open parts of the vein, such as rep-

resented in the first specimen (Fig. 1). Open vugs, lined with quartz, chalcedony, and a green tabular mineral, mark the final disappearance of the solution.

Phenomena of this same order, although not so striking, are common. For example, at the zinc mines at Mascot, in Tennessee, the ores occur in Paleozoic dolomite, and the primary ore is almost exclusively yellow blende, with a dolomite-calcite gangue. The ore occurs in a brecciated zone. Wilbur A. Nelson, state geologist [1] says:

> It occurs in the brecciated horizon as veinlets, irregular masses of variable size, fracture fillings, and breccia cement. Gangue minerals occurring with the sphalerite are dolomite and calcite. The quantity of sphalerite is variable, generally being greater in the more intensely brecciated rock. . . . The ore does not occur continuously along the strike of the rocks in the zone just above the contact between the Canadian and Ozarkian, but occurs in shoots irregularly spaced. These ore shoots vary from 100 to 200 ft. in width and are an intensely brecciated zone varying from 25 to 120 ft. in thickness. The ore in these brecciated shoots varies in richness, containing from 1 to 5 per cent. metallic zinc. These shoots are irregular, tortuous, and more or less connected. Their distribution is irregular.

Mark H. Secrist [2] says:

> As has been repeatedly stated, the ore is associated with brecciated horizons in the country rock. The origin of the brecciation is not at all times clear, particularly when no visible planes or movement can be seen. On the other hand, at the Felknor mine, the Fall Branch mine, New Prospect, etc., direct evidence of brecciation associated with faulting is at hand. The breccia is usually made up of sharp-angled fragments of the country rock cemented by a matrix, which consists of variable amounts of white or gray dolomite, some calcite, chert, sphalerite, galena, and pyrite. It should be mentioned that galena is found only in a few districts and is not a widespread constituent of the breccia filling.

I went under ground in October, 1924, and collected specimens which I shall describe. I noted that "Nearly all the ore is in fissure fillings, occurring in many small veins of white dolomite

[1] *Trans. A. I. M. E.*, Birmingham meeting, Oct., 1924: "Mascot, Tenn. Zinc Ores," pp. 7, 8.

[2] Cited by Nelson, *op. cit.*, p. 10.

which reticulate the gray dolomite of the ore horizon sharply. This dolomite incloses blende. Sometimes there is a definite fine banding (crustification) of these veinlets. These veins join to form large ore masses, inclosing angular broken blocks of white or gray dolomite." (Fig. 11.) Later I studied the specimens,

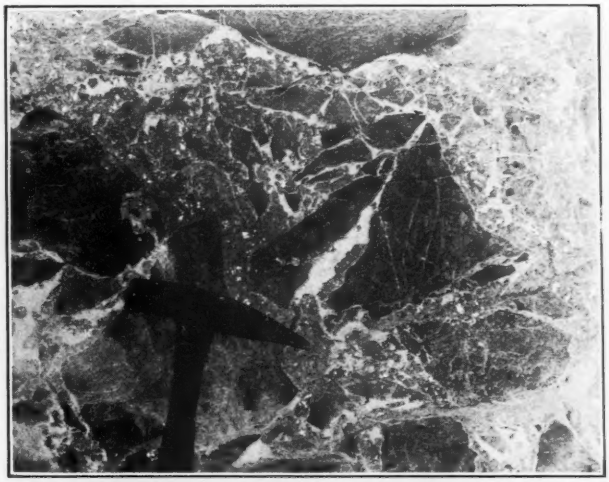

FIG. 11. Photograph of zinc ore in stope, at Mascot mine, Tennessee. Ore cements a dolomite breccia.

including one with a sawed surface given me by Mr. Blair, of Birmingham (Fig. 12), and perceived that all the specimens showed a definite successive crystallization, from the included fragments out. The fragments are also of different types of dolomite—different in color and in texture, and with different orientation, showing that they represent pieces mixed together, not residua of replacement. In some cases these fragments touch; but rarely.

They are invariably surrounded by an envelope of bluish-gray carbonate, probably dolomite, about one eighth of an inch thick

(Fig. 12). The outer margin of this envelope shows a continuous line of well-developed crystal faces, showing that these crystals grew out into a fluid (the alternative of open spaces being negatived by the almost invariable separation of the fragments one from another). The rest of the interspaces is occupied by practically contemporaneous pinkish dolomite and yellow blende.

FIG. 12. Photograph of sawed surface of zinc ore from Mascot mine, Tennessee, showing toothed "collar" of dolomite crystals around fragments of dolomite rock. Diameter of specimen about three inches.

In some places the blende, in others the pinkish carbonate, is moulded on to the toothed collar which surrounds the rock fragments. There is, however, evidence of a delicate succession of crystallization within the blende itself: for the light-yellow blende, free from iron, has a distinct tendency to border the fragments, outside of the carbonate spiked collar, while slightly darker blende occupies the centers. There is no sharp line between these two shades of blende, however, showing that the two are parts of a single crystallization stage. (Tiny veins of white carbonate cut all the foregoing.)

In this connection deserves mention the "grande antique marble," used for decorative finish in buildings, and said to come from Jeumont, France. I am trying to obtain geological descriptions of this occurrence. Meanwhile, the polished slabs on the outside of the Hotel Roosevelt, in New York, extending around the whole block, form a magnificent geological exhibit (Fig. 13).

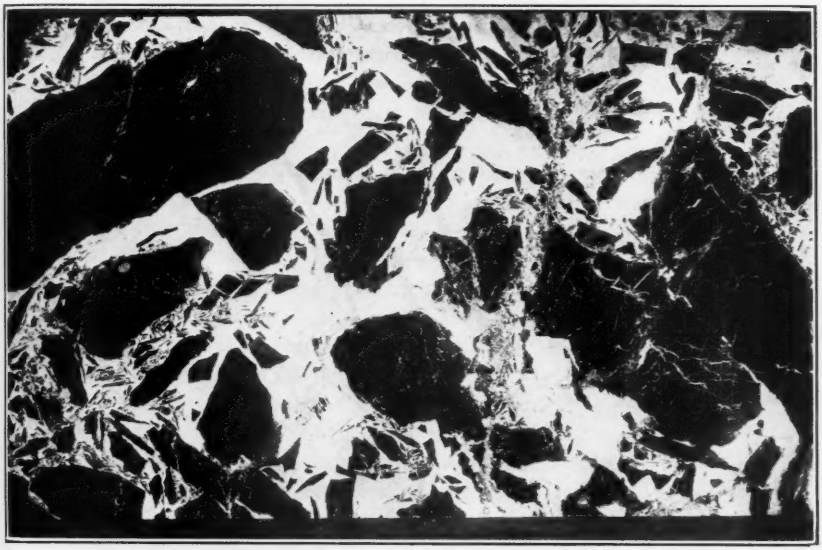

FIG. 13. Photograph of slab of "grande antique" marble at Hotel Roosevelt, New York. Height of slab about 8 feet.

The decorative effect is due to blocks of black bituminous (locally fossiliferous) limestone inclosed in an abundant white matrix. The polishing reveals a definite and universal though delicate banding of the matrix, hardly noticeable on the rough fracture; and the banding is moulded on to the included fragments, showing that crystallization began on those surfaces. The first deposition is an opaque white dolomite, in which fine parallel banding

may be detected; and in residual areas left by the growing together of this dolomite, is colorless calcite, as determined by Prof. J. Volney Lewis.

I believe nearly anyone who will walk around this block and study the exhibit carefully will conclude that these limestone fragments have been suspended and isolated in a solution which was capable of supporting them—the white cementing material was not deposited from circulating waters, but was the result of crystallization, in situ, of a highly concentrated solution. Yet this

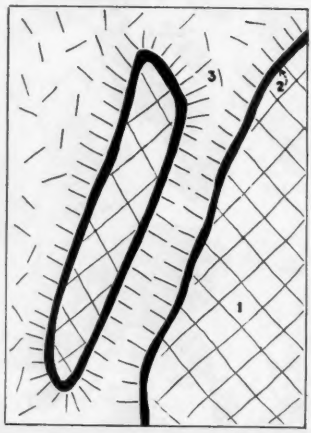

FIG. 14. Analytical sketch of portion of specimen of silver-lead ore from Villemagne mine in France. Diameter of field sketched about two inches. 1, silicified limestone (jasperoid) largely replaced by blende and galena (pyrite); 2, galena; 3, comb quartz, near the broken fragments of (1), developing into granular quartz away from the fragments.

solution was, when it burst into the black limestone, a clear solution: all crystallization succeeded emplacement, and there are no signs of flow structure. In this "grande antique" stone the process of continued splitting up of the black limestone fragments into smaller fragments may be observed in all stages, and

the word which seems most descriptive of this is spalling. It seems that the cementing solution, penetrating into crevices, had an expanding and a prying power.

The specimens which I have described show almost exclusively phenomena of injection and show little important evidence of replacement. Specimens which have been sent to me by Mr. H. H. Knox, from Villemagne, a silver-lead-zinc mine in the south of France, show evidence of injection and successive crystallization, and also of replacement by the injected fluids. The history of these specimens I interpret as follows:

A. Partial replacement of a dense, dark, shaly limestone by pyrite, blende, and galena (1, Fig. 14).

B. Shattering of the ore and rock by the injection of a siliceous vein magma. Inclusion of ore and rock in angular detached floating fragments.

C. Deposition of galena from the fluid magma in rims around the included fragments (2, Fig. 14). (The galena is presumably argentiferous.) This stage shows that the crystallization of galena was in general later than that of blende, so that the sequence indicates falling temperature.

D. Movements within the vein magma, separating the angular fragments into new fragments: so that some of these have the galena band on one margin but not on the others.

E. Crystallization of quartz, as a growing fringe or halo with comb or toothed structure, crystal terminations pointed outward. Growth of this shows in fine banding of the quartz, the different toothed layers of quartz crystals having built one upon the other (3, Fig. 14).

F. Further partial fragmentation, involving all of the foregoing, and due to the injection of more quartz, and barite.

One of the specimens shows the entire inside of the angular included fragments (everything except the galena collar) eaten out and the space partly taken up by little druses lined by quartz crystals. The fragment on which the collar grew is entirely gone (Fig. 15).

FIG. 15. Analytical detail of portion of another specimen of same ore as Fig. 14. Diameter of field sketched about three inches. Shows (2) typical galena rims of fragments; (3) crystalline quartz, containing geodes. (3) has not only disrupted but has entirely replaced the original limestone angular fragments on which (2) was moulded, although it has not attacked noticeably the jasperoid and sulphide fragments shown in Fig. 14. The quartz which has replaced the fragments is, as indicated, finer grained than the quartz between the fragments.

Referring back to the "orbicular vein" of Zacualpan, I wish to quote an observation by Mr. S. J. Truscott, who, among other professional work, has translated into English the "Ore Deposits" of Beyschlag, Vogt, and Krusch (Macmillan, 1914). The subjoined passage was a part of a discussion of the paper by Hatchek and Simon on Gels in Relation to Ore Deposition.[3]

Mr. S. J. Truscott said that he had had occasion at one time to be working on a mine where there was a considerable amount of banded quartz. The reef belonged to the Tertiary gold-silver orebodies, an important group. Towards the hanging wall the ore was richest, and there the banding was very close, resulting in the formation of a dark-colored leader; on either side of this the banding became more open. Towards the footwall, however, there was a different occurrence; here there was an arrangement of the banding concentric to rounded or sub-angular fragments of the country rock. This ore they generally spoke of as *ringel-erz*, the German term for ore of that description. He understood

[3] *Trans. Inst. Min. and Metal.*, 1911–12, pp. 473–474.

the authors to say that the banding was the result of a reaction proceeding from the walls and therefore parallel to them. This would, however, not account for the concentric banding. Perhaps the authors, however, could apply their reasoning to produce not only the parallel but also the concentric banding. With regard to these fragments in the footwall, it was rare that in any section there was sufficient evidence that without their quartz envelopes they support one another by touching. Originally, before they were thus enveloped, how were they supported in the fracture? It has been suggested that actual contact between the fragments did actually take place more than the evidence would lead one to suppose, but that the growth of the envelopes caused in some cases a separation, the fragments having been apart. It appeared to him that that might be true with the smaller fragments but not with the larger. It could be more easily imagined that they were supported by the silica in a gelatinous condition. He supposed the ordinary idea was that these crusts were gradually formed as film after film was slowly deposited. There was, however, no reason to accept the gradual filling of a fracture as the only possible occurrence. In the lavas which have poured out from Vesuvius it has been recorded that large fractures became filled with mineral deposits in a short time. As in all these Tertiary gold-silver reefs, where the filling was chiefly of silica, *the formation of the reefs* marked the last stages of *a dying vulcanicity;* it was quite possible that they *were also formed quickly, so quickly as to provide a support for the fragments in the fractures.*

The fact that gelatinous silica contained so much water, together with the assumption as a speculation that the reefs were first filled with this silica, might offer an explanation of the vugs so often found with these reefs, viz., that the silica in becoming desiccated shrunk to leave a central space.

In this paper I have cited instances where breccias appear to have been formed by the injection of a concentrated and dense solution, capable of holding for a considerable period fragments of the invaded rock in suspension. In all the cases I have mentioned there has been a successive precipitation around these fragments from the inclosing fluid, these bands demonstrating that the isolated fragments were the nuclei outward from which crystallization progressed, and were not the centers toward which crystallization proceeded—in other words, that they were not residua of replacement. I have carefully refrained from discussing the origin of the dense solution in this paper, my purpose being to

show that the work of water is much exaggerated in orthodox geologic conceptions. Neither are these bands to be explained as contemporaneous with one another, according to the theory of vein banding advocated by Hatchek and Simon,[4] based upon the phenomenon of the Liesegang rings due to chemical reactions in gels or colloids. The phenomena show the bands are due to a succession of crystallization; and in two of the specimens described I have detected evidence of falling temperature during crystallization.

FIG. 16. Photograph of specimen from one of the silver-bearing veins of Cobalt, Ontario. Width of specimen, three inches.

In closing I wish to show the photograph (Fig. 16) of a specimen from a vein at Cobalt, Ont. The white filling of the Cobalt veins appears to be homogeneous and without evidence of concentric growth around included fragments; so that the origin of the fragments as residua of replacement has been argued. On observing, however, that the fine banding in the "grande antique"

[4] "Gels in Relation to Ore Deposition," *Trans. Inst. Min. and Met.*, 1911–12, pp. 451–480.

stone was clear only on a polished surface, I examined my rough specimens of Cobalt veins attentively, and did indeed detect a faint banding parallel to some of the fragments, which on polished surfaces might be plainer. In the photograph a regular band of calcite about ⅜ of an inch thick around the wall rock inclusions, is free from metallic minerals; outside of which rim, however, the metallic minerals occur mingled with similar calcite.

NEW YORK CITY.

OIL AND GAS ACCUMULATION IN THE CLINTON SAND OF OHIO.[1]

WILLIAM L. RUSSELL.

INTRODUCTION.

THE oil and gas pools in the Clinton sand are of interest to petroleum geologists because of the unusual conditions under which production is found. In particular they afford a means of estimating the relative importance of the rôles played by buoyancy and the various other processes that bear on oil and gas accumulation. After the numerous false structures due to stratigraphic causes have been eliminated, it appears that in regions in which the producing sandstone is quite lenticular and entirely devoid of water many of the oil and gas pools occur in zones of small folds which increase in intensity downwards. The processes which cause the oil and gas to accumulate in these folded areas in the absence of water may also operate in the more normal areas in which the sandstones are saturated with water outside the limits of the pools.

ACKNOWLEDGMENTS.

The data on which this paper was based were gathered by the writer while engaged in making a study of the Clinton Sand Oil and Gas Pools for the East Ohio Gas Company in the first half of 1924. The object of this investigation was to ascertain what methods could be used to predict new oil and gas pools or extensions of the old ones. Acknowledgments are due to the geological force of the East Ohio Gas Company, particularly J. R. Lockett, for maps, well logs, elevations and other data, and to the Klise, Eckstein & McCann Drilling Company for well logs.

PREVIOUS WORK.

In recent years a number of publications dealing with the oil and gas pools in the Clinton sand of Ohio have appeared. The

[1] Published by permission of the East Ohio Gas Company.

structures of the producing areas have been described as monoclines, anticlines, terraces, synclines, "wavy structures" and zones of folding. In the Bremen Oil Pools Bownocker [2] has suggested that oil accumulated at the lower termination of sheets of the Clinton sand, with gas higher up the dip to the west, and that the separation of the oil from the gas in accordance with its specific gravity has been promoted by the shallow synclinal structure of the pools. Horn [3] in discussing the structural terraces of the gas pools near Cleveland states that "the occurrence of such flats between the pitching areas would tend to cause the accumulation of gas or oil, because at such places they would have little tendency to move farther." The mechanism which would cause the gas to move at all is, however, not stated. Bonine [4] mapped a sharp anticline, the crest of which follows closely the long, narrow gas pool west of Wooster which is shown in Fig. 1 of this paper, and stated that this anticline was responsible for the gas accumulation; he did not, however, discuss the process which caused its accumulation. His structure map is, moreover, based on the top of the Clinton sand, which is, as will be shown below, untrustworthy as an index to the structure, and at the time his paper was published the Wooster Oil Pool was largely undeveloped. Conrey,[5] writing when the northeast trend of the oil pool had been revealed, states that it is on a fold extending in that direction. This conclusion is contrary to the findings of the present paper, and may be based on the false structures caused by stratigraphic irregularities in the Clinton sand. Rogers [6] concluded that the gas of the Clinton sand fields has migrated up the dip and accumulated just east of the belt where the sand pinches out, and that the gas pools in the vicinity of Cleveland are located

[2] Bownocker, J. A., "The Bremen Oil Field," Geological Survey of Ohio Bull. 12, 1910, p. 24.

[3] Frank R. Horn, "Reservoir Gas and Oil in the Vicinity of Cleveland, Ohio," *T. A. I. M. E.*, vol. LVI., 1916, p. 842.

[4] C. A. Bonine, "Anticlines in the Clinton and Sand near Wooster, Wayne County, Ohio," U. S. G. S. Bull. 621, pp. 87–98.

[5] G. W. Conrey, "Geology of Wayne County," Geological Survey of Ohio, Fourth Series, Bull. 24, 1921, p. 128.

[6] G. S. Rogers. The Cleveland Gas Field, U. S. G. S. Bull. 661–A, 1917.

chiefly on anticlinal noses. In a recent article Lockett [6a] mentions the occurrence of production in areas of structural disturbance. He says (p. 76): "Sub-surface structure maps covering a number of townships where there has been extensive drilling showed that production does not conform to the general structure. From these maps it does not seem that the relative positions of the oil and gas in the reservoirs depended upon their specific gravities," but states further on (p. 79): "A number of intersecting cross sections drawn through closely drilled territory showed that accumulation followed logically the structure within the Clinton but seldom conformed to the more general structure of the region. . . . Where there is gas it usually accumulates on the higher parts of these structures, within the Clinton, and the oil is ordinarily found in the basins."

In the literature published up to the present time there has been no explanation of the processes which have caused oil and gas to accumulate in these anticlines and zones of folding in a sand wholly devoid of water, or of the bearing of these processes on our ideas of oil and gas accumulation in general. It is the purpose of the present paper to discuss these problems.

STRATIGRAPHY.

A brief description of the stratigraphy of the region is necessary for the understanding of the struuctural relations and the methods of investigating them. The exposed rocks in the eastern portion of the belt of Clinton sand production are chiefly shales and thin sandstones and limestones of Mississippian age, in which no reliable key beds for mapping the structure are known. Further east and southeast Pottsville strata of Pennsylvanian age are found, but unfortunately they, at least in their lower portions, are so lenticular or are deposited on such uneven surfaces that they are of doubtful value as indices of the structural details.

Beneath the surface are 400 to 1,000 feet of Mississippian shales, which are underlain by the Berea sandstone, the first reli-

[6a] J. R. Lockett, "Notes on the Clinton Sandstone in Ohio," *National Petroleum News*, Oct. 29, 1924, pp. 73, 75, 76, 79, 81, 83.

able key horizon of the region. The latter is an extremely widespread and persistent horizon, generally from 5 to 80 feet in thickness. Below it are 700 to 1,500 feet of Mississippian and Devonian shales, largely black or brown and bituminous, which are called in the well logs the Ohio shales. The great series of Devonian and Silurian limestones, which are next encountered in drilling, are grouped together in the well logs as the Big lime. Salt water is often encountered in one, or occasionally two, horizons 100 to 300 feet below the top of the Big lime, and in a horizon about 100 to 200 feet above its base. In the northeastern portion of the field a bed of salt lies near the middle of the Big lime. In the portion of the field treated in this paper the Big lime ranges from 800 to 1,500 feet in thickness. Between the Big lime and the Clinton sand are 100 to 300 feet of shales of Silurian age, containing one or more beds of limestone, called the Little lime or Lime Shell. The Clinton sand itself is a gray, pink or reddish sandstone, which may be encountered anywhere in a zone 150 feet thick immediately under the Little lime. It is extremely variable in its thickness and character. In some places it consists of several separate beds of sandstone, which may run together or pinch in neighboring wells. Often drillers report broken sand or sand mixed with shale, and sometimes only a few feet of sand, but some sandstone is nearly always encountered at the Clinton sand horizon.

Below the Clinton sand is the red Medina shale, of Silurian age, which is several hundred feet in thickness, followed by 1,000 feet, more or less, of Ordovician shale, containing a considerable amount of dark or black bituminous shale.

GENERAL CONDITIONS.

Regional Stratigraphic and Structural Relations.—The regional dip of the strata in the Clinton Gas Field is east or southeast, and this is still further increased at the horizon of the Clinton sand by the thickening of the Ohio shales and the Big lime in those directions. In a general way, the amount of deformation may be said to increase towards the southeast throughout the gas field, and still

further southeast are the strong folds of the Appalachian type. The source of the Clinton sand was towards the east, and in that direction the sediments change from the marine to the continental type.

Zones of the Clinton Sand.—The progressive change in the stratigraphy, structure, and depth towards the east-southeast may be utilized to divide the region of the gas fields into several belts or zones, extending north-northeast, in each of which the general conditions are similar. In the first zone, to the west and northwest of the gas fields, the Clinton sand is absent, as it was not laid down that far from the shore of the sea. Further east-southeast it begins to appear in patches, and finally, in the second zone, forms a broad belt of comparatively thin and uniform sheets, that extends from near the shore of Lake Erie almost to the Ohio River. The greater thinness and uniformity in thickness of the sand in this zone as compared to the belts to the southeast, where it is continental in origin, suggests that it is either an off-shore deposit or a sheet of sand laid down on the seaward margin of the great delta, where the relief was slight and the currents comparatively gentle. In this belt the deformation is comparatively slight, and the structure generally monoclinal. The depth of the sand is much less than in the zones to the southeast, being not much over 2,000 feet. Owing to the comparatively shallow depths and small amount of deformation, the sand has not been subjected to such great pressures as it has to the southeast, and consequently it is relatively soft and porous. In fact, in parts of this belt it is so soft that wells in it are not shot, a condition which is not found farther east. The production is here presumably limited by the extent of the sand bodies, and as these are much more uniform and extensive than farther east, the pools are correspondingly larger.

In the third belt to the east the Clinton is thicker, more irregular and lenticular, deeper and harder. The oil and gas pools are surrounded by wide stretches of barren territory. The production seems to be closely related to zones of folding, though it is known to occur in monoclines also. The eastern margin of this zone has

not yet been determined, but production has already been found at depths of about 3,500 feet. On account of the greater depth and deformation, the Clinton sand here is, in general, much harder, and many dry holes are caused by its being too dense to yield oil or gas. Owing to the fact that there appears to be some relation between the production and the structure, this belt is the most interesting of all. It is the only one of the zones which was studied in detail by the writer.

To the east and southeast of the productive territory is a great area in which the Clinton is so hard and tight that it has yielded only shows of oil and gas. The intense pressures due to the great depth and proximity to the strong folds of the Appalachian type are probably responsible for the low porosity of the sandstone. The Clinton in this region is much greater in thickness than further west, and usually consists of many separate sandstone strata, some of which are reddish, separated by shales which are also in part red. In fact, it is possible that sandstones would be found scattered through the whole of the red Medina shale if a well were drilled through it near the bottom of the Appalachian geosyncline, for this formation becomes more sandy towards its source. Shows of oil and gas are encountered in the Clinton in this zone, and the rock pressures are probably very high. As already stated, it is not yet known how far down into the Appalachian Geosyncline the production will extend, but so far no gas or oil have been produced at depths greater than 6,000 feet, and only insignificant production from depths between 5,000 and 6,000 feet.

Carbon Ratios.—The fixed carbon ratios of the coals in Eastern Ohio do not afford a satisfactory index to the alteration of the Clinton sand, for the progressive increase in fixed carbon content towards the southeast is more or less masked by the considerable differences between the fixed carbon content of different beds, due apparently to original chemical differences, and by the fact that coals of higher horizons are exposed to the southeast. Owing to its greater depth and greater age, the Clinton Sand is more highly altered than the Pennsylvania strata in which the coals occur, and this difference is much greater towards the southeast, where the

interval between the Clinton and the base of the Pennsylvanian is greater. However, in spite of the various complications enumerated, a general progressive increase in the fixed carbon content of the coals towards the southeast may be detected, and up to the present time no oil and gas production has been obtained from the Clinton where the fixed carbon content of the coals (on a moisture and ash free basis) is over 57.5 per cent.

METHODS OF MAPPING THE STRUCTURE.

In studying the oil and gas pools in the Clinton sand the greatest care must be taken to separate the apparent structures due to lenticularity, deposition on uneven surfaces, the occurrence of strata at different horizons, and other purely stratigraphic irregularities, from the true structures due to deformation. Failure to discriminate between these two different sets of phenomena has led to erroneous conclusions being drawn as to the structural relations of the oil and gas pools.

In mapping the structure the geologist must make use of the horizons that are commonly recorded in the well logs. In addition to the Clinton, six horizons are commonly logged. They are the top and base of the Berea sandstone, the Big lime, and the Little lime. The salt water horizons in the Big lime are either not found or not recorded in many wells, and unfortunately drillers often fail to record the salt, which would probably make a good key bed. The Berea sandstone serves as a satisfactory key horizon over most of the gas field, but in certain areas, as in the northeastern part of the Wooster Oil Pool, shown in Fig. 1, it varies irregularly in thickness, and is thoroughly unsatisfactory. The top of the Big lime in certain regions, as in the Wooster Oil Pool, makes an excellent key bed, but the base is highly irregular, and is of little use. The Little lime over much of the Clinton sand territory makes an excellent key bed, but it must be used with caution, for in some places it varies 30 feet or more in thickness within short distances, and furthermore there sometimes are two or more beds of limestone between the Clinton and the base of the Big lime, and it is often impossible to correlate these between

wells. Hence it is safe to say that what is logged as Little lime is not always the same stratum.

It should be obvious from what has been previously stated about the Clinton that it is thoroughly untrustworthy as a key bed. Its great irregularities in thickness, its occurrence at different hori-

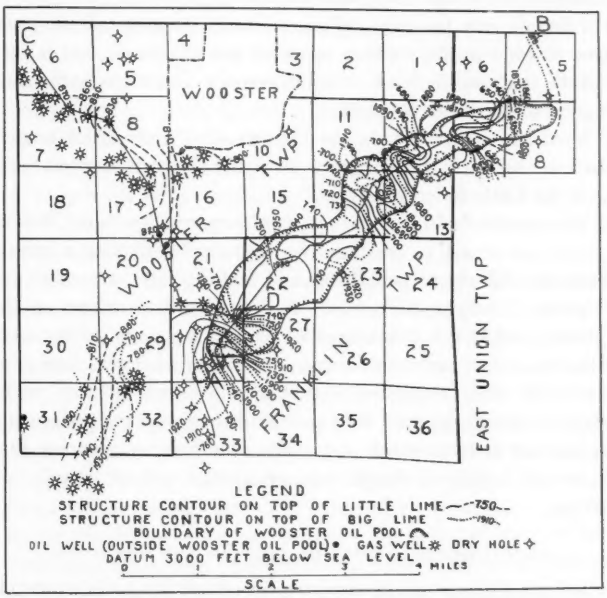

FIG. 1. Structure map of Wooster oil and gas pools.

zons, and the presence in some areas of several sandstone strata which cannot be correlated between wells, all introduce such large errors that it is safe to say that most of the supposed structures based entirely upon the elevations on the Clinton sand are due chiefly to such stratigraphic causes and not to true deformation. Where the folds are large and steep they will show up in the Clinton, as for example the anticline west of Wooster mapped by Bo-

nine and shown also in Fig. 1. Most of the structures, however, are so small that they would be apt to be masked by the stratigraphic irregularities.

It should be understood that the remarks made in this paper, unless otherwise stated, are intended to apply to a region in northeastern Ohio in the third zone of the classification given below. Conditions may be quite different in various parts of the great area covered by the Clinton sand oil and gas fields, and it may well be that further west or southwest the Clinton is sufficiently regular to serve as a key bed.

Most of the writers on the Clinton sand have unfortunately used it chiefly in mapping the structure, though Lockett [7] has used the Little lime.

The conditions in the gas pool in Chippewa Township, Wayne County, serve well to illustrate the necessity for making a careful distinction between true deformation and the false structures due to purely stratigraphic causes. A structure map drawn on the Clinton sand in this township showed large apparent folds. Another structure map with contours drawn on what was logged as the Little lime suggested different and much gentler folds. When, however, sections were plotted through the gas pool, using all the key beds to check one another, it became apparent that there was merely a simple monoclinal dip with practically no folding.

STRUCTURAL RELATIONS OF THE OIL AND GAS POOLS.

A Typical Case.—After studying the oil and gas pools in several counties in northeastern Ohio, the writer became convinced that they were related to zones of folding. As so many supposed folds in this area have been shown to be due solely to the irregularities in the original sedimentation, and as these zones of folding have an important bearing on the processes of accumulation of the oil and gas, it seems advisable to give in full the evidence for their existence. This can best be done by the presentation of a typical case. The oil and gas pools in the vicinity of Wooster, Wayne

[7] *Loc. cit.*, p. 79.

County, are chosen for this purpose because they are fairly typical of the conditions, and because the evidence concerning them is nearly all in. Other oil pools, as in Monroe and Hardy townships, Holmes County, were only being developed when studied by the writer.

The anticline west of Wooster has already been mapped by Bonine, but at the time his map was prepared the oil pool was largely undeveloped, and furthermore his structure contours are drawn on the Clinton sand. Fig. 1 shows a structure map of these oil and gas pools drawn on the top of the Little lime and the top of the Big lime. The locations of the wells are taken from the maps of the East Ohio Gas Company. A few of the elevations of these wells were supplied by the geological department of the East Ohio Gas Company, but most of them were obtained by the writer with a hand level.

Evidences of Folding.—The anticline west of Wooster shows up in the Little lime as well as in the Clinton, and, as stated by Bonine,[8] in the Berea also. Owing to the difficulty in identifying old wells and to the incompleteness of some of the well logs, sufficient data were not obtained by the writer to map it in detail. An anticline approximately in line with this, apparently its southeastern continuation, cuts across the southwestern portion of the oil pool. As the Little lime, the top of the Big lime and the Berea are all folded, there is no doubt of its being a genuine fold. In the remainder of the oil pool there is a series of narrow folds, which extend parallel to the anticline west of Wooster, and not, as Conrey stated, at right angles to it. The similarity of the folding in the two horizons removes all doubt as to its being genuine.

Downward Increase in Intensity of Folding.—A peculiar feature of the folding is that it is more intense in the lower horizons. It is evident from Fig. 1 that the Big lime is folded more feebly than the top of the Little lime, and the folding is still feebler in the Berea. In fact, the folds in sections 7 and 8, East Union Township, and the northern half of section 12, Wooster Township, do

[8] Bonine, *op. cit.*, p. 95.

not show up at all in the Berea. A few minor irregularities in the Little lime, as in the eastern half of section 14, Wooster Township, do not appear in the top of the Big lime, and the salt also lies flat across some of them. They are probably due to the deposition of the Little lime on uneven surfaces, though they may also be genuine folds formed in Silurian time.

Effect of Irregularities.—Fig. 2 illustrates the irregularities of the Clinton sand in these pools, such as its sudden variations in thickness and its occurrence at different horizons. The remarkably uneven character of the base of the Big lime is evident. In the southeastern portion of section C–D there is some uncertainty as to whether there are two Little limes, one of which pinches out, or whether the limestone stratum is continuous, as is suggested in Fig. 2. It is obvious that the Clinton sand is thicker in section A–B, which runs through the oil pool, than it is in section C–D. This greater development of sand along the long, narrow strip covered by the oil pool is probably in part the cause of its trend. It is likely that the southeastern boundary of the oil pool is determined by a change in the character of the sand. If, as is suggested, the sand body extends in a northeasterly direction and terminates or changes rather abruptly to the southeast, its extent roughly parallel to the shore line at the time it was laid down suggests that it is an off-shore bar or beach deposit. It should not be supposed that the presence of a beach deposit at one point would mean that all of the Clinton sand to the east, towards the land, would be continental. The sea level was probably more or less variable during the time when the 150 feet of strata in which the Clinton occurs were laid down, and bars and beach deposits may have been formed during successive stages of its advance over the land.

Separation of Oil and Gas.—In the area covered by Fig. 1 it is evident that there is no marked tendency for the oil to be synclinal and the gas anticlinal. The Wooster Oil Pool, in fact, cuts across several anticlines and synclines. It should be noted, however, that the gas occurs up the dip from the oil, and that the chief oil accumulation, the Wooster Oil Pool, is on the down dip side of

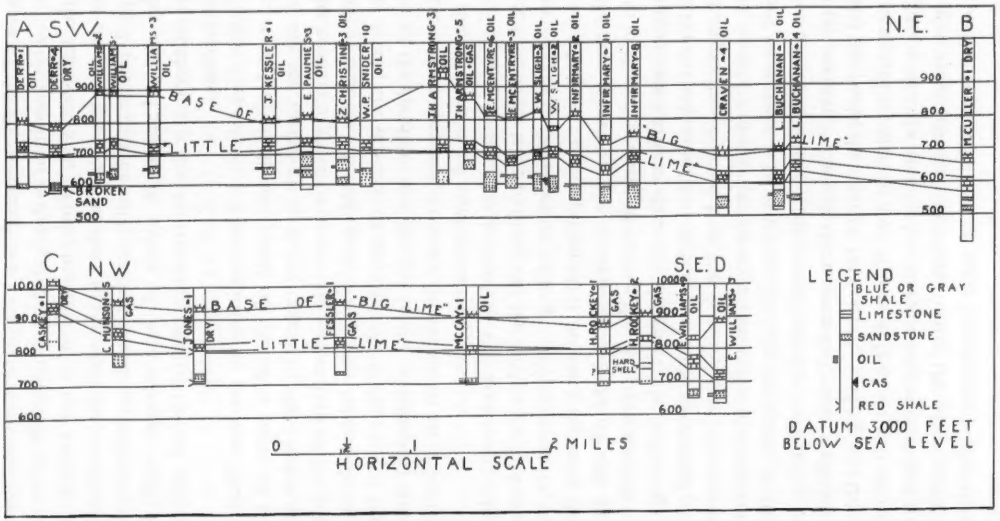

FIG. 2. Sections through Wooster oil and gas pools.

an area of the Clinton sand in which there is oil and gas production. This condition is duplicated in some of the other oil pools of the Clinton sand. Unfortunately it is not known definitely what changes take place in the Clinton sand just southeast of the oil pool, but it may be inferred that it either pinches or becomes shaley or hard and tight. Any of these changes might be sufficient to check any downward migration of the oil and cause an accumulation.

Typical Conditions.—The conditions in the area illustrated by Figs. 1 and 2 which are typical of the other parts of the third zone, are the variations in the thickness of the Clinton sand and in the horizon in which it occurs; the association of the productive areas with zones of folding in which the folds become steeper with depth; the absence of any definite tendency for the oil to occur in the synclines and the gas in the anticlines of these small folds; and an apparent tendency for the oil to occur on the down dip side of an area of sand containing gas.

Relation of Production to Folds.—The area covered by Fig. 2 is not sufficiently large to bring out the tendency of the productive areas to occur in the zones of folding. When, however, structure maps of large areas are prepared, it becomes apparent that folds of the type shown in Fig. 1 occur among the oil and gas pools, while in the intervening dry areas the structure contours show a comparatively uniform dip. As, however, the wells are crowded together in the productive territory and widely scattered outside of it, it might be objected that the few wells in the unproductive areas would be insufficient to reveal the zones of small folds even if they were there. In order to eliminate the effect of this factor as far as possible, the writer constructed a map using only one well per section. Though there were still more wells among the oil and gas pools, the relation between the folding and the production was still so marked that it was difficult to refrain from the conclusion that the folding has in some way contributed to the oil and gas accumulation. Lockett,[9] using the same methods, has independently arrived at the same conclusion. The remarkable

[9] *Op. cit.*, p. 76.

manner in which some of the pools follow certain folds, such as the anticline west of Wooster, is in strong support of this supposition.

Age of the Folding.—There are a number of reasons for supposing that the narrow folds, such as form the zones of deformation in the producing areas, were not formed during the Appalachian Revolution at the close of the Paleozoic. As is suggested by Fig. 1, the direction of these folds is often northwest-southeast, nearly at right angles to the prevailing trend of the Appalachian structures. Moreover, contouring the folds on different key horizons, as in Fig. 1, shows that these folds grew in size during at least three different periods. Folding began during the Silurian or Devonian, and was repeated along the same axes in the Upper Devonian or Lower Mississippian. A final folding took place after the Lower Mississippian.

While it is not possible to date definitely the folds which deform the Berea, it is quite likely that they were not formed at the same time as those of the typical Appalachian type found further southeast, for they are quite different in type and direction. Moreover, in Tuscarawas County,[10] Ohio, there are some folds of Early Pennsylvanian age which have a certain resemblance to the structures of the producing areas. Many of the folds in Tuscarawas County are also unlike the Appalachian type in the direction of their axes, and most of them are small and steep, some even dipping at angles of over 60 degrees. Innumerable faults are present, and the Mahoning sandstone, which overlies some of the folds and faults unconformably, serves to date them. The Clinton sand in this locality contains gas under great pressure, but as it is very hard and tight the production is small. The similarity of these early Pennsylvanian folds in Tuscarawas County to those in the zones of folding of the producing areas suggests that some of the latter may also have been formed at this time. In certain parts of the Clinton Gas Field there are, however, folds of larger size which are roughly similar in direction to the normal Appalachian type. These may well have been deformed during the Appalachian Revolution.

[10] Edward Orton, Geol. Surv. of Ohio, vol. 5, p. 278.

THE ABSENCE OF WATER.

All those who have written on the Clinton sand in northeastern Ohio are agreed that it is devoid of water. The frequent occurrence of red shales above the Clinton and the fact that the Clinton sand itself is often red suggests that the climate of that time was in part arid or semi-arid. Hence the absence of water may be explained by evaporation under desert conditions before the deposition of the basal portions of the Big lime.

THE EFFECT OF POROSITY ON PRODUCTION.

The general decrease in the porosity of the Clinton sand towards the southeast has already been mentioned. In the eastern part of the gas fields it has long been recognized that the sand varies greatly in porosity, and many dry holes have been attributed by producers to its hard and tight condition. The low porosity of the sand in certain wells is indicated by the difficulty with which it drills, the appearance and hardness of samples of it, and the fact that the production of wells producing under high pressure from clean sand of good thickness is often small. In order to obtain some idea of the porosity the writer made determinations of two samples. One sample from the "Stray" sand of the Clinton in a well on the A. W. Lotimer farm in Lot 29, Canaan Township, Wayne County, was found to have a porosity of 7.0 per cent. The initial production of the well was 800,000 cu. ft. per day, and the sample appeared hard and tight. The other sample was from D. Wiles No. 2 of the Creston Gas Company in Lot 21, Canaan Township, Wayne County. Its appearance was comparatively soft and porous, and the porosity was found to be 12.4. These determinations were made by the acetylene tetrachloride method described by the writer elsewhere.[11]

THE ORIGIN OF THE OIL AND GAS.

That the oil and gas in the Clinton sand did not originate in the overlying black bituminous Ohio shales is indicated by the comparative absence of production in the water horizons near the

[11] Manuscript in preparation.

top and base of the Big lime. If oil and gas had migrated down through the whole thickness of the Big lime it is reasonable to suppose that they would have accumulated more abundantly in these horizons than in the Clinton below. As the shales between the base of the Big lime and the Medina are occasionally black, it is possible that some of the oil and gas has originated in them, but as most of these shales are bluish-gray or reddish in color, it may be doubted if there was enough bituminous matter in them to have formed such enormous quantities of gas and oil. The Medina shale is largely reddish and devoid of organic matter, and it is therefore not likely that it could have served as a source rock. A more likely source is the great mass of black or dark colored shale of Ordovician age which lies below the Medina.

It has long been known that the rock pressures of the oil and gas pools in the Clinton sand were not related to hydrostatic pressures. It may be inferred, therefore, that the pressure is determined simply by the ratio of the volume of the oil and gas to the size of the reservoirs. It is generally supposed that the effect of an increase in pressure on reactions is to promote those which tend to relieve the pressure, and inhibit those which increase it. Hence if the oil and gas, which occupy a larger volume than the substances from which they were derived, were unable to escape, an increase in pressure would tend to prevent the formation of these fluids. Under these circumstances oil and gas could not be formed from solid substances of greater density by the agency of pressure alone. If, however, the solids were under differential pressure, and the oil and gas were free to escape, then the pressure would tend to promote their formation, for the conversion of a solid substance to a fluid which could escape would relieve the pressure. If the volume of the source rock were large, and the volume of the reservoir into which the oil and gas were escaping was of limited size, then the pressure might accumulate until it grew so great that the formation of more oil and gas was prevented. As the pressure on the solid rocks of the earth's crust increases with depth, pools of oil and gas formed in this manner

might show a general increase in pressure with depth, as is the case with those in the Clinton sand.

PROCESSES OF OIL AND GAS ACCUMULATION IN THE CLINTON SAND.

The occurrence of oil and gas in anticlines and terraces in sands containing salt water has been explained by the theory that these structures check the migration of the oil or gas due to their buoyancy, causing them to accumulate in the fold. When, however, oil or gas is found to be concentrated in folds in areas in which the sand contains no water, some other explanation must be looked for.

If the folds produced a concentration of gas in the anticlines with oil in the synclines, this relationship could easily be explained. What is found, however, is the occurrence of gas in anticlines or zones of folding surrounded by areas which produce neither oil nor gas, and the accumulation of both oil and gas in these folds surrounded by territory which is either absolutely dry or yields only shows of oil and gas.

It is the opinion of many of the geologists who have worked on the Clinton sand that the gas has undergone extensive migration, and that its occurrence in the folds is caused by its movement being arrested where the dip changes. Horn,[12] as already mentioned, has suggested that terraces in the Clinton sand near Cleveland have caused accumulations of gas or oil in this manner. To the writer, however, it appears that there has been no very extensive migration of gas in the eastern portion of the gas field, and that, even if such an extensive migration had taken place, there would have been no tendency for the gas to accumulate in the anticlines or terraces in a sand devoid of water and containing very little oil.

There are a number of reasons for supposing that the Clinton sand in the third zone mentioned above is so lenticular that such an extensive migration along the beds would not take place. The occurrences of the Clinton sand at different horizons, its separation in many places into three or more distinct strata which

[12] *Op. cit.*, p. 842.

cannot be correlated between wells, the presence of oil at higher levels than the gas in the same sand in adjacent wells, and especially the great variations in the initial closed pressure in adjacent wells, all indicate that the Clinton sand is composed of more or less disconnected lenses. The irregular variations in pressure have been noted by nearly all those who have written on the Clinton sand in Ohio. Pressures sometimes vary within short distances from about 200 lbs. per sq. in. to nearly 1,200 lbs. per sq. in. Such variations in many cases cannot be due to the exhaustion of the rock pressure with continued production, for the wells with the higher initial pressures are sometimes drilled in later.

If the Clinton sand contained considerable quantities of oil it might be supposed that a migration of gas would take place up the dip. Such is far from being the case, however. The content of oil in the Clinton sand is insignificant compared to the gas. There are only a few oil pools in the Clinton sand as large as the Wooster Oil Pool shown in Fig. 1, and their occurrence is thus highly exceptional. In most of the areas of Clinton sand production gas wells alone are found, though there are occasional oil wells or wells having shows of oil in some of the gas pools.

It is true that there is a general though very irregular increase in the rock pressure towards the east, where the sand is deeper. It might be supposed, therefore, that the gas had moved up the dip from regions of greater pressure to lesser. If the Clinton sand were continuous and the decrease in pressure towards the west uniform, there would be good reason for supposing that this was the case. When, however, the sand is known to be so lenticular that great differences in pressure can exist within a few thousand feet, it seems obvious that migrations across vastly greater distances would be impossible.

Even if such a migration did take place, however, there would still be no reason for the accumulation of gas in the anticlines or terraces. As the migration would be caused only by pressure differences, and not by buoyancy, a change in dip would have no effect on its progress. It should not be necessary to state that

gas, when present alone, will spread uniformly over the whole of the containing space, and will not be concentrated in the higher parts, as it will when fluids of greater density are present.

It appears to the writer, therefore, that other processes than those just discussed must have operated to cause the oil and gas to accumulate in folds in the Clinton sand. Two processes may be suggested to account for this accumulation: the oil and gas may have been formed from their parent substances in greater quantity in the vicinity of the folds than elsewhere, and the fractures produced by the folding may have afforded passageways for the migration of the oil and gas from the source rock to the oil and gas sands, so that they reached the latter in greater quantities in the folded areas than elsewhere.

There are a number of reasons for supposing that oil and gas would be developed in greater quantities in folded areas than in territory which was not deformed. While there is still much that is in doubt about the mode of origin of oil and gas, many geologists are of the opinion that pressure, heat or the shearing or distortion of the source rocks have played an important part. The distortion or shearing of the rocks, due to the differential motion in deformation, is obviously greater in folded areas than in regions not deformed. Owing to the friction produced by the shearing, the heat must also have been greater, and possibly the pressure was greater as well. As the migration along the strata in the Clinton sand is difficult, if the oil and gas were formed in greater quantities in the folds they would still be found in their vicinity in greater abundance than elsewhere.

While the process just described may have played a part in producing the accumulations of oil and gas in the folded areas, it is probably not so important as the effect of the fracturing. There is every reason to believe that the movement of oil and gas through the exceedingly small pores between the grains of shales and limestones would be extremely slow, even if it could take place at all. If these pores were wet the movement of oil and gas through them would be opposed by great capillary forces. Hence unless the rock from which the oil and gas were formed were in direct con-

tact with the producing formation, these fluids might not be able to reach the latter simply because of the absence of joints or fissures through which they could move. There can be little doubt that joints, fractures, and possibly small faults are more abundant in the folds of the Clinton oil and gas field than they are in the adjacent undeformed areas. Such fractures would be especially abundant and well-developed over the anticlines, because of the tension along their axes. Hence a larger volume of oil and gas has been able to reach the Clinton sand by migrating across the strata in these deformed localities than in the adjacent monoclines. Once in the sandstone it is not able to move far along the strata, and consequently the oil and gas pools are located in the vicinity of the folds.

THE RÔLE OF DEFORMATION IN OIL AND GAS ACCUMULATION.

Sands which, like the Clinton, are lenticular and devoid of water, serve to indicate the part played by factors other than buoyancy in causing the accumulations of oil and gas in anticlines, terraces and other types of folds under normal conditions. Where the sand contains water it is usually impossible to tell whether buoyancy alone has caused its accumulation, or whether other factors too have assisted it. In cases where the sand is devoid of water but persistent over wide areas the oil and gas would spread out over such a large region that their relation to the folds might be masked. The occurrence of oil and gas in folded areas in the Clinton sand suggests, therefore, that the same processes which cause their accumulation in the folds there may also assist the buoyancy in causing their accumulation in anticlines and terraces in the sands which are saturated with water beyond the producing areas. There is every reason to suppose that, if in the Clinton sand folding has caused the formation of oil, or if the attendant fracturing has allowed it to migrate into the reservoir rocks, folding in the water-bearing sands would act in the same manner.

If this is the case it might be expected that, when these water-saturated producing sands were highly lenticular, or when they

were so impervious as to make migration through them difficult, there might be evidences of a tendency for the production to follow the areas of deformation as well as the closed folds or other structural traps. Under such conditions there are sometimes indications of this. For example, in the Glenn Oil Pool[13] there is no closed structure, but the production is found in an area of plunging parallel folds.

The oil and gas pool in Brown Township, Knox County, might also be cited as an illustration of this tendency. In that locality there is a fairly large fold on which oil and gas production is found in the Berea sandstone, and gas in the Clinton. The fold is much steeper on the east than on the west. The regional dip of the Berea is towards the southeast, but is exceedingly small. It contains some salt water outside the limits of the pool. Though very persistent, it is rather impervious, as is indicated by the small size and long life of the wells. The striking fact is that some of the best production in it occurs at the foot of the fold towards the east, where it is steepest—in other words, just where it would not be expected to be if the accumulation were due entirely to the migration of the oil due to buoyancy.

CONCLUSIONS.

1. Towards the east and southeast the Clinton sand increases in irregularity and decreases in porosity.

2. In the eastern portion of the gas fields it consists of many disconnected lenses.

3. Owing to the increase in depth and decrease in porosity towards the southeast the chances for finding commercial production in the Clinton sand decrease in that direction, and the outlook is particularly unfavorable for the areas in West Virginia, Southeastern Ohio, and Southwestern Pennsylvania where the Clinton is over 6,000 feet deep.

4. While no single key horizon is always reliable as an index to the structure of the Clinton sand, a good idea of the deformation

[13] Smith, C. P., "The Glenn Oil and Gas Pool and Vicinity, Okla.," U. S. Geol. Surv. Bull. 541, pp. 34–48, 1912.

affecting it may be obtained by using several different strata at once.

5. In many of the pools there are zones of folds which were formed at several different periods in the Middle and Late Paleozoic.

6. There is apparently a tendency for the oil and gas to occur in these zones of deformation rather than in the intervening monoclinal areas.

7. Production in the Clinton sand should be sought in folded areas, but it is not likely that it can be predicted with as much success as in the water-bearing sands.

8. There has been no very extensive migration of oil and gas in the eastern part of the gas field, and the occurrences of oil and anticlines are not due to the arresting of the movement by the change in dip.

9. The tendency of the oil and gas to occur in these folds may be ascribed to its greater generation in them or to the fractures developed by the folds, which may allow the oil and gas to reach the oil sand in greater quantities.

10. These same processes may assist buoyancy in causing the accumulation of oil and gas in folds in sands saturated with water.

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THE SIGNIFICANCE OF HEMATITE IN CERTAIN ORE DEPOSITS.

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INTRODUCTION.

THIS paper completes[1] the abstract of a study of hematite, magnetite, and sulphide minerals, and of the balance between oxidation and reduction in sulphide ore deposits. The study, which was carried on in the Harvard laboratories, was suggested by Prof. L. C. Graton, and I am indebted to him for much aid and criticism. Acknowledgments are also due to Dr. Alfred Wandke, who had been working on the same problem and gave me the benefit of his data and much helpful discussion, and to the other members of the Harvard Geological Department.

The study was undertaken in an attempt to check the hypothesis advanced by Professor Graton and his colleagues of the Calumet and Hecla geological staff to account for the copper deposits of Michigan. Their hypothesis held that the copper was brought in by sulphur-bearing solutions, and that the main cause of the precipitation of native copper (instead of the usual sulphides) was the oxidation of the sulphur by the hematite contained in the rocks—an explanation which had previously been advanced by Steinmann[2] for the Corocoro deposits of Bolivia. It is supported, among other things, by the observed tendency for the country rock, normally red, to be bleached in the vicinity of the copper, the bleaching being due to the removal of hematite or to its more or less complete conversion to ferrous compounds.

It seemed advisable to look for traces of analogous processes in sulphide deposits. In the country rock of sulphide ore bodies

[1] See also "The Antipathy of Bornite and Pyrrhotite," ECON. GEOL., XX., 1925, pp. 364–370, and "Some Magnetite-Hematite Relations," *idem*, pp. 587–596.

[2] Steinmann, G., "Die Entstehung der Kupfererzlagerstätten von Corocoro," Rosenbusch Festschrift, 1906, pp. 335–368.

hematite is not usually abundant, but there are many cases in which it is found as an ore mineral, apparently formed by the very solutions which deposited the sulphides. In such cases the hematite is normally older than the sulphides, and it might therefore be expected to exert upon them something of the same oxidizing action as the rock hematite of the Michigan basalts and conglomerates.

SCOPE AND METHOD OF INVESTIGATION.

One of the most obvious methods of attacking the problem was by the study of the relations of hematite to magnetite. Hematite is ferric oxide, Fe_2O_3. Magnetite is ferroso-ferric oxide, $FeO.Fe_2O_3$. They frequently occur in close association, and they seemed, therefore, to afford a useful index to conditions of ore deposition, for the replacement of one by the other would presumably indicate a dominance of oxidation or reduction, as the case might be. It is well known that magnetite sometimes undergoes hypogene alteration to hematite, and, on the other hand, Wandke had found that hematite in several sulphide deposits had been wholly or partially replaced by magnetite. The objects of the study were to determine how, when, and in which direction the change usually proceeds, and whether it is related in any definite way to the formation of the sulphides.

The main method employed was the microscopical examination of the two minerals, in their relations to each other and to the accompanying sulphides and gangue. The material for study was in part collected during a summer spent in visiting mining districts in the western states and Canada, in part it was obtained from suites in the Harvard laboratories. All available material from sulphide ore bodies, which contained magnetite or hematite, was utilized. The microscopical work was, of course, supplemented as fully as possible by field observations, by megascopical study of specimens, and by a careful combing of the literature.

The question of the relation of ferric iron to the sulphides speedily became entangled with another question recently raised

by Butler.[3] Butler has pointed out that in zones of contact metamorphism the ferric: ferrous ratio is usually higher than it is in igneous rocks, on the one hand, or in lower-temperature deposits, on the other. Early in my own work I found corroboration for this in the fact that contact deposits were the most fruitful source, not only of ferric silicates, but of the oxide minerals which I was seeking. Butler has suggested that this abundance of ferric iron may be due to the oxidation of ferrous iron in the magmatic solutions by the carbon dioxide of the invaded limestones. In the same paper he has discussed briefly the possible reduction of ferric oxides by sulphur compounds, and has made the important observation that in general the contact deposits (or parts of deposits) which are richest in ferric oxide are poor in sulphur. My own survey of contact metamorphic and other deposits leads me to agree with Butler's views; the antipathy between ferric oxide and the sulphides seems to be borne out in a fairly definite way both by the microscopical relations of magnetite and hematite and the large-scale facts of their occurrence.

HEMATITE AND PYRRHOTITE.

The data appeared for a long time to be hopelessly chaotic. The hematite found in association with sulphides quite often showed signs of reduction to magnetite, but, on the other hand, magnetite not infrequently showed oxidation to hematite, even with sulphides close by. In fact, it seemed to be a very general rule that whichever mineral formed first should be more or less altered to the other. The first fact which appeared to have real significance was the observation that in the ores of Ducktown and Sudbury (both of which were studied in the field and by means of large suites of specimens) there is no idiomorphic hematite, and the magnetite, which occurs in small amounts, shows no trace whatever of hematitic alteration. Both these ores are of the heavy pyrrhotite type, and a tentative working hypothesis was therefore set up that hematite is not found in pyrrhotite ores.

[3] Butler, B. S., "Suggested Explanation of the High Ferric Oxide Content of Limestone Contact Zones," ECON. GEOL., XVIII., 1923, pp. 398–404.

This proved to hold in the four other localities from which I collected pyrrhotite specimens, namely, Rossland, B. C.; the Sullivan mine at Kimberley, B. C.; the Hecla and Success mines in the Cœur d'Alenes; and the Gossan Lead, Va. Each of these contains a little magnetite, but no hematite at all was observed. Microscopical study of pyrrhotite-magnetite specimens from a few other localities gave similar results. The literature seems to support the rule; I have found practically no references to hematite as a primary constituent of pyrrhotite ores.[4]

The deposits enumerated above belong for the most part in the deep vein zone, a zone in which conditions are admittedly reducing and in which hematite is usually absent or very scarce, while even magnetite does not occur in very large amounts in sulphide ores. In contact metamorphic ores the iron oxides are more abundant and their relations to the sulphides more complex. For this type also, however, the hematite-pyrrhotite rule appears to hold, and it has been of service in classifying my data and reducing them to something approaching a state of order.

CONTACT METAMORPHIC DEPOSITS.

The contact deposits on which I had any data, either first or second hand, practically all filled the following conditions, which are typical of the class as a whole. They occur in limestone or other lime-rich rocks, at or near an intrusive contact, or exceptionally they are within the intrusive close to a limestone contact. The intrusives are in almost all cases moderately or strongly acidic. There is a good development of the lime-silicate minerals, of which the most important is, of course, garnet. Magnetite is present in all.

The lime silicates of the contact zones are frequently conspicuous for the amount of ferric oxide they contain. Andradite and epidote, two of the commonest of these silicates, are rich in

[4] The literature is as usual a doubtful guide. "Hematite" often means limonite, or at least a product of supergene oxidation. As most descriptions are not backed by microscopical study, it is usually impossible to get any information as to whether the magnetite shows any replacement by hematite.

ferric iron, and others, such as biotite and vesuvianite, contain important amounts. Hematite is 100 per cent. ferric oxide, magnetite 70 per cent. Ferrous iron, however, is by no means negligible, and such minerals as magnetite, actinolite, biotite, ilvaite, hedenbergite, and fayalite contain much of it.

Lindgren's group of "deposits due to igneous metamorphism" includes two main classes, the chalcopyrite deposits ("principal ore minerals are chalcopyrite, pyrite, pyrrhotite, zincblende, molybdenite, magnetite, and specularite")[5] and the magnetite deposits. The chalcopyrite deposits are the commoner, but the two are not separated by any hard and fast line; the iron oxide deposits usually contain some sulphides and the sulphide deposits some iron oxides. The normal paragenesis of these classes seems to be about as follows: First come the ferric-lime silicates, and then (overlapping) magnetite. Then (again overlapping) comes one of three sequences. (1) Hematite is found in large amount, partly contemporaneous with the magnetite, but chiefly later and to some extent replacing magnetite. (2) Hematite is entirely absent, but instead there is a development of sulphides, usually in abundance, including pyrrhotite. (3) The intermediate case. There is some development of hematite with and later than the magnetite, followed by more or less sulphide, but no pyrrhotite. In this third case the amount of hematite is roughly in inverse ratio to the amount of sulphides; if sulphides are abundant, hematite is not, and such hematite as occurs is altered, at least in part, to magnetite.

So far as can be judged from my own studies, the majority of contact deposits can be assigned with some definiteness to one or other of these three groups. No matter how many other factors may enter in, there remains a visible antipathy between ferric oxide (and especially hematite), on the one hand, and the sulphides (and especially pyrrhotite), on the other. In most cases the balance is fairly even; the intermediate class is much greater than either of the end classes; but I believe that study of any given contact deposit will nearly always bring out a conflict be-

[5] Lindgren, W., "Mineral Deposits." 2d edition, 1919, p. 725.

tween two opposing tendencies, one tending to produce oxidation and the other reduction.

The Hematite Group.—Small magnetite deposits, poor in sulphides and carrying appreciable amounts of hematite, are widely scattered. Because they are usually small and poor in sulphides they are generally of little economic importance; the descriptions in the literature are often brief and vague, and there are scarcely any published reports of microscopical or microphotographic examination of the ores. Deposits like Iron Springs, Utah,[6] Dayton, Nev., Heroult[7] and Eagle Mountains,[8] Calif., eastern Porto Rico,[9] Bulacan in the Philippines,[10] Magnitnaia,[11] in the Urals, and some of the Banat deposits[11] of Hungary appear to belong here. Each of these is characterized by a scarcity of sulphides and an abundance of hematite. Daiquiri, Cuba, is of this or a closely related type, though there is some doubt as to whether it can be accurately called a contact metamorphic deposit.

The Pyrrhotite Group.—Contact deposits containing pyrrhotite are fairly common in some parts of the world. Along the Coast Range batholiths they are found rather frequently. They are usually associated with the sulphides of copper, lead, and zinc, with pyrite and magnetite, but not with hematite. Numerous small deposits of this sort in western British Columbia and Alaska are mentioned in reports of the Canadian and American Geological Surveys. As a rule they contain the usual lime silicates and magnetite, but they seem to be nearly free from hematite. The few specimens which I have examined from ores of this sort contain none, and in British Columbia, so far as I can find, the min-

[6] Leith, C. K., and Harder, E. C., "Iron Ores of the Iron Springs District, Utah," U. S. G. S. Bull. 338, 1908.

[7] Prescott, B., "Occurrence and Genesis of the Iron Ores of Shasta County, Calif.," ECON. GEOL., III., 1908, pp. 465–480.

[8] Harder, E. C., "Iron-ore Deposits of the Eagle Mountains, Calif.," U. S. G. S. Bull. 503, 1912.

[9] Fettke, C. R., "Magnetite Deposits of Eastern Porto Rico," *Trans. A. I. M. M. E.*, LXX., 1924, pp. 1024–1042.

[10] Pratt, W. E., "Iron Ores of the Philippine Islands," *Trans. A. I. M. M. E.*, LIII., 1915, pp. 90–105.

[11] Beyschlag, Vogt, and Krusch, "Deposits of the Useful Minerals and Rocks."

eral is not mentioned in any of the descriptions. In Alaska the deposits of Copper Mountain and Kasaan Peninsula have been described in considerable detail by Wright.[12] In his general description of the contact deposits of the region (which contain magnetite and chalcopyrite, usually with pyrrhotite), he states that "nearly all the deposits contain small amounts of specularite or micaceous hematite," but in the detailed reports on individual properties there are only two references to this mineral, and in neither of them is pyrrhotite mentioned. Without laboring the point, it may suffice to reiterate the two things which seem to be important. First, in the literature I can find no description of any pyrrhotite ore body which contains appreciable amounts of hematite. Second, I have not been able to find any pyrrhotite specimen which contained idiomorphic hematite[13] or in which the magnetite showed any alteration to hematite. This applies both to contact ores and to all other ores which I have studied microscopically.

The inference seems to be that it is difficult, if not impossible, for the ferric oxide hematite to form or exist under conditions suitable for the formation of the ferrous sulphide pyrrhotite. Hematite either did not form at all or, if formed, was destroyed during the formation of the pyrrhotite. Under such conditions magnetite, in spite of its ferric oxide content, is more stable than hematite. It is frequently found with pyrrhotite, but even in this case the antipathy is visible; where pyrrhotite is abundant magnetite is not, and vice versa. Finally, the ferric oxide in the silicate minerals is more stable still, and these silicates are about as abundant in pyrrhotite ores as in hematite ores.

Pyrrhotite deposits usually contain a fair abundance of sulphides. It is true that the relations of pyrrhotite to pyrite, as determined by laboratory experiments,[14] are controlled mainly by

[12] Wright, C. W., "Geology and Ore Deposits of Copper Mountain and Kasaan Peninsula, Alaska," U. S. G. S. Prof. Paper 87, 1915.

[13] The only exceptions were one or two specimens which contained a few very minute grains of hematite, recognizable only under the high power and tightly sealed in quartz or silicate gangue.

[14] Allen, E. T., Crenshaw, J. L., and Johnston, J., "The Mineral Sulphides of Iron," *Am. Jour. Sci.* (4), 33, 1912, pp. 169–236.

temperature, but these experiments were carried out in an atmosphere of hydrogen sulphide—*i.e.*, under reducing conditions and in presence of excess sulphur. It is therefore arguable, and I believe true, that these conditions are necessary if pyrrhotite is to form at all. The idea, sometimes expressed in the literature, that because pyrrhotite contains less sulphur than pyrite it is to be regarded as a product of sulphur-poor solutions, is one for which there seems to be little or no geological evidence. In ore bodies which contain only small amounts of sulphur, that sulphur is more likely to be found in pyrite than in pyrrhotite.

A noteworthy feature of the pyrrhotite deposits is their abundance along the Pacific batholiths. The tendency for pyrrhotite to occur in deposits connected with intrusives of large size, and to be absent from somewhat similar deposits connected with intrusives of smaller size, is worthy of thought. In Arizona and the neighboring states of the Basin-and-Range province, pyrrhotite is remarkably scarce. The contact deposits of the larger camps, at least, are practically free from it—certainly free from large bodies of it. On the other hand, along the Pacific, in the Precambrian, and in general in the regions of large intrusives, pyrrhotite contact deposits and pyrrhotite lenses of various sorts are more common. The temperature factor by itself is hardly adequate to explain this, for some of the contact deposits of the Basin-and-Range province must have been formed at temperatures high enough for pyrrhotite to flourish. This question will be returned to further on in this paper; but the subject of the range of pyrrhotite would probably repay a more exhaustive study than it has yet received.

The Intermediate Group.—Between the two end members there is a large intermediate group, which does not exhibit clearly the characteristics of either extreme. These intermediate deposits often contain hematite, but never very abundantly; they ordinarily contain abundant ferric-lime silicates and considerable magnetite; they occasionally contain a little pyrrhotite; they usually contain a fair amount of other sulphides. The hematite, when it occurs, is normally earlier than the sulphides and most abundant

where the sulphides are scantiest, and where it occurs in close association it always shows at least traces of reduction to magnetite. The magnetite-hematite relations, however, and especially those seen under the microscope, are likely to be complex in these ores. As stated in my previous paper, replacement often seems to work both ways within the limit of a single specimen, governed apparently by purely local conditions. In many of the ores the story told by the microscope is quite incoherent; but the larger relations outlined in the preceding paragraph will nearly always be found to hold, and the deposits, viewed in this light, fall naturally into place as examples of a state of balance between the "excess oxygen" of the first group and the "excess sulphur" of the second.

This type is much commoner than either of the preceding ones and includes the contact deposits of most of the camps of the Southwest—Morenci is perhaps as good an example as any. Such hematite as occurs in these bodies is most commonly associated with magnetite in distinct lenses or pockets, the magnetite being the essential mineral and the hematite a more or less variable accessory. These pockets are closely related to the main sulphide masses in space and probably in time, and in composition there is some overlapping—the pockets carry a certain amount of sulphide and the sulphide bodies a certain amount of iron oxide—but on the whole the large masses of oxides are distinct from the sulphides.

HEMATITE IN OTHER TYPES OF DEPOSIT.

The contact deposits, as already stated, provided most of the material for study because of their especial richness in ferric minerals. The cause of this richness, of the oxidizing tendency which seems to oppose the reducing action of the sulphides, is a question outside the scope of this paper, though there would seem to be much support for Butler's hypothesis regarding the oxidizing power of the carbon dioxide in limestone. Except in limestone, hematite is but a rare and scanty constituent of sulphide ore bodies. On the other hand, there are at least a few cases of limestone

ores which contain both abundant sulphides and abundant hematite. In the Old Dominion mine at Globe, hematite occurs in small quantities in the heavy sulphide ore, and the large pockets of iron oxides which are found in and near the ore bodies are nearly pure hematite, instead of the more usual case of magnetite, with minor amounts of hematite. The Globe deposits were probably formed at temperatures well below those of the ordinary contact deposits, and it may be that at lower temperatures the hematite becomes increasingly stable in the presence of sulphur solutions. In some of the Bisbee mines, likewise, the magnetite lenses contain rather large amounts of hematite (chiefly replacing the magnetite). The Bisbee ore bodies are sometimes considered to be of contact metamorphic origin, largely because of their strikingly regular arrangement around the periphery of the intrusive; but they have no very great development of the orthodox lime silicates, and they appear to represent only a mild sort of contact action.

On chemical grounds one might perhaps expect hematite to be more stable than magnetite at low temperatures. The reactions $2FeO + O = Fe_2O_3$ and $2Fe_3O_4 + O = 3Fe_2O_3$ are exothermic and would therefore tend to be favored by falling temperatures. These equations, of course, take no account of the original condition of the ferrous oxide and oxygen; and obviously one must use caution in applying any such data to the complex and largely unknown reactions accompanying ore deposition.

In deposits of the deep vein zone hematite is rare, while pyrrhotite is relatively common. Of the deposits assigned by Lindgren to this class the greater number are gold ores, and in these pyrrhotite is a frequently mentioned accessory. The veins of the southern Appalachians, of Porcupine, of the Homestake, of southeastern Alaska, of Minas Geraes, and of western Australia all contain it. The only mention of hematite which I have found is at Kalgoorlie.

The tin deposits, formed as a rule at depth and in close proximity to granitic intrusives, sometimes contain pyrrhotite and

sometimes hematite. Ferguson and Bateman[15] give a table summarizing the mineral associations in twenty of the most important tin districts. Pyrrhotite and hematite are each mentioned seven times, but only once from the same region (New South Wales). Tin ores are characteristically low in sulphur, so it might be expected that if hematite were to appear at all in this zone it would be in ores of this type.

The magnetite ores of the Adirondack-New Jersey types, whatever their relations to the igneous rocks with which they occur, are certainly of high-temperature and high-pressure origin, and therefore more or less closely related to the deep veins. They normally contain small to large amounts of sulphur and little or no hematite.

The heavy sulphide ores formed at depth usually carry much pyrrhotite, and so far as my knowledge goes hematite is entirely lacking from such ores.

In general, there seems to be little tendency for hematite to form in the deep vein zone. This is in accord with the accepted belief that there is no excess of oxygen in this zone.

In lower-temperature veins hematite is again scarce. There are numerous cases where it is found occurring with sulphides, but not in large amounts. In the Pilares mine, Nacozari, a pyrite-chalcopyrite ore body in latite and andesite, it is found here and there in the sulphides. It is usually corroded by the sulphides; in some cases it shows considerable alteration to magnetite, in others it seems to be on its way to complete removal or replacement by carbonates. More rarely it is quite unaltered. At Jerome, at Virgilina, and elsewhere, hematite is occasionally found in similar conditions. Very rarely (as in a few specimens from Globe) part of the hematite appears to be younger than the sulphides.

These occurrences are interesting mineralogically, as showing the ability of hematite to persist under certain conditions in the presence of considerable amounts of sulphides, but quantitatively

[15] Ferguson, H. G., and Bateman, A. M., "Geologic Features of Tin Deposits," ECON. GEOL., VII., 1912, pp. 209–62.

they are of insignificant importance; they do not at all alter the general rule that there is little ferric oxide in these sulphide ore bodies.

THE SIGNIFICANCE OF HEMATITE AND PYRRHOTITE.

In the foregoing pages an attempt has been made to show that hematite and pyrrhotite represent respectively the extremes of oxidizing and reducing conditions, and that when found in contact metamorphic deposits they correspond broadly to a scarcity or an abundance of sulphides. It has been suggested further that pyrrhotite is most likely to be found in those contact deposits which are connected with large intrusives. The following paragraphs contain some speculations as to the meaning of this.

Lindgren's classification of ore deposits contains, among other things, three groups of hydrothermal deposits, formed respectively near the surface, at intermediate depths, and in the deep vein zone—the epithermal, mesothermal, and hypothermal classes of his newer terminology. In the first group temperature and pressure are both regarded as being low, in the second both are moderate, and in the third both are high. The "deposits formed by processes of igneous metamorphism" are considered to be produced at still higher temperatures and pressures. That is, in the whole series temperature and pressure vary together, though, of course, Lindgren recognized exceptions. Similarly the deposits of Emmons' "reconstructed vein system"[16] are arranged in a single vertical line from batholith roof to surface. It seems to me that instead of there being a single major variable, the depth at which the deposit was formed, there are two to be taken into consideration: first, the depth of the ore deposit below the surface; and, second, the depth from which the solutions come (or, alternatively, the distance of the ore body above the source of the solutions).

The essential factors in the formation of any ore mineral or group of minerals are, of course, the chemical conditions—the

[16] Emmons, W. H., "Primary Downward Changes in Ore Deposits," *Trans. A. I. M. M. E.*, LXX., 1924, pp. 964–997.

nature of the chemical system comprised by the ore solutions and the invaded rock—and the physical factors of temperature and pressure. The pressure is dependent mainly on the weight of the overlying rocks, and the isobars are therefore approximately horizontal. The temperature, on the other hand, is greatly influenced by the proximity of the intrusive, and the isotherms are therefore deflected in its neighborhood from their ordinary horizontal position. The result, as pointed out recently by Rastall,[17] is that instead of temperature and pressure varying together the isotherms and isobars cross at large angles near the intrusive, and there can be a wide range of pressure for a given temperature and vice versa.

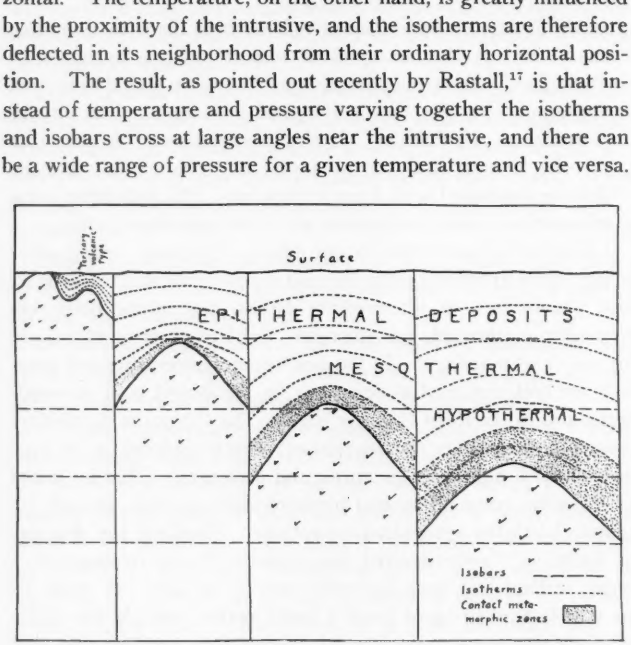

FIG. 1.

Fig. 1 is an attempt to set up a classification on this basis. The figure represents a series of intrusives, each of which is idealized into a stock with ore solutions rising vertically from its summit. The isobars are shown as horizontal lines, the isotherms as lines which curve around the intrusive.

[17] Rastall, R. H., "Metallogenetic Zones," ECON. GEOL., XVIII., 1923, pp. 105–121.

The "Tertiary volcanic" type of deposit is shown on the extreme left. These were formed close to the surface by emissions from magmas which were themselves close to the surface. In these, contact metamorphism is insignificant. Next to them come what may be called the "near-shallow" deposits of the San Juan type, deposits which are intermediate between the epithermal and mesothermal classes. The intrusives which produce these may have a contact aureole, but it is likely to be narrow. Third come the stocks, rather more deeply buried, which produce the ordinary intermediate deposit. In this case the zone of contact metamorphism is wider, because temperatures and pressures are higher. Finally, on the right, are the still deeper (and usually larger) intrusives responsible for the ores of the deep vein zone. These may also have their zones of contact metamorphism, and above them is a type of deposit formed at considerable depth, but also at a considerable distance above the intrusive, a type which may be represented by some of the Cœur d'Alene ore bodies. Still farther above would come the near-surface veins formed by solutions which have risen a great distance, a class which might include some at least of the lead-zinc, fluorite, and barite deposits, which are commonly interpreted as the work of meteoric waters.

The diagram indicates a narrow zone of contact metamorphism around the second stock, a wider one around the third, and a still wider one around the fourth. (The temperatures around the fourth, however, are perhaps so high as to discourage deposition of ore at the immediate contact; the tendency in the case of the Precambrian batholiths, for instance, is for the ores to be found at some distance from the actual contacts.) This implies that the contact deposits can grade over into ores of various types, that in one district they may be associated with rather shallow deposits and in another with those of the deep vein zone.

Contact action, of course, is dependent upon chemical conditions as well as physical. The veins within the roof of a stock may have been formed at temperatures and pressures as high as those of the neighboring contact metamorphic deposits; but the reactions which go on in the just-solidified igneous rock, whatever they may

be, do not produce anything resembling that which we know as contact metamorphism. The diagram attempts to indicate the zone within which contact deposits *may* occur; but if chemical conditions are unfavorable, and especially if limestone is lacking, it is unlikely that they *will* occur.

However, even if chemical conditions were similar, there would remain physical differences between deep and shallow contact deposits. Where cooling was rapid, as in the case of a small intrusive which attained to within a short distance of the surface, conditions might change radically during the period of emission of ore solutions. The first emanations would travel through fissures in the invaded rocks and produce their contact action. The loss of heat, however, would be rapid; contraction, and especially differential contraction, would speedily make itself felt; and in a short time the whole top of the intrusive would have solidified and been fractured. The later solutions, instead of following in the same paths as the earlier ones, would impregnate the shattered top and escape, largely through newly formed channels, to the surface.

But in the case of a batholith or stock cooling at considerable depth, the change in conditions produced by the solidification of the upper part of the igneous mass would not be so great. There would be less differential contraction, less general fracturing of the igneous rock, more restriction of the fracturing (and therefore of the solutions) to particular shear zones. The later solutions, as a result, would be more likely to follow the same paths as the earlier ones.

Now it is from the later solutions that the sulphides are deposited. The rule in nearly all contact deposits is that the sulphides are younger than the silicates, and the sulphides of the rarer metals younger than those of iron. The contact metamorphism, the development of the garnet zones, is performed at an early stage, and performed mainly by the introduction of silica, iron, etc.—the common rock-forming oxides. Later—perhaps close behind, but nevertheless later—come the sulphur, copper, etc., the products presumably of a more extreme differentiation.

My conception is that the early magmatic solutions produce the lime-ferric silicate zone, which is for some reason (probably because of the carbon dioxide reaction) a zone of oxidation. The question, then, is whether this zone of oxidation is to be maintained against the later sulphur-rich solutions. The result depends on (1) how much sulphur the later emanations contain, and (2) how closely they follow in the path of the earlier ones. If there is little sulphur, or if the sulphur solutions are not confined to the paths followed by the earlier solutions, then the ferric minerals persist and continue to form. If, however, there is much sulphur, and the sulphur solutions follow essentially the same channels as the earlier ones, then the tendency will be for the ferric oxide minerals to be destroyed.

The ideas of depth and of size of intrusive are rather hard to keep separate. The preceding paragraphs have perhaps carried the implication that deep intrusives are necessarily large and shallow ones necessarily small. But after all a small intrusive is merely a part of a larger one, a part which has performed a certain amount of intrusion on its own account and which may have been more or less effectually sealed off from its parent; and this independent intrusion and subsequent sealing-off are certainly more likely to occur near the surface than at depth. The sealing-off, if it does occur, will obviously diminish the supply of mineralizers; the small intrusive will then have only its own content of volatiles with which to mineralize the surrounding rocks, whereas an intrusive in direct connection with its source of supply might go on receiving magmatic heat and emanations for a much longer period.

This means, in brief, that the conditions postulated as favorable to the persistence of a state of oxidation—scarcity of sulphur-bearing solutions and their failure to follow in the path of the earlier solutions—are most likely to be found in connection with small intrusions; and the reverse conditions are most likely to be found in connection with larger intrusions. The small sealed-off intrusion is not likely to occur at great depth. The larger intrusion, on the other hand, may attain to within a short distance

of the surface; in fact, the only upper limit to its progress, apparently, would be the total engulfing of the roof, which would presumably put an end to the formation of contact deposits.

The hematite class, on this hypothesis, is one extreme. Oxidation was intense at an early stage, and it was never overcome. Magnetite, the higher temperature oxide, was replaced by hematite as the temperature fell, because there was not enough sulphur present to exert any effective reducing action. Each of the two reasons for the lack of sulphur may have contributed to this result—an actual scarcity of sulphur to the smallness of the intrusive or to a scarcity in the magma itself, or failure of the sulphur to follow in the path of the earlier solutions.

The pyrrhotite class is the other extreme. Oxidation was again intense at an early stage (though perhaps not quite so intense as in the hematite deposits) and the ferric silicates were able to form in abundance; but there followed soon afterwards enough sulphur to exert a strong reducing effect and consequently to impede greatly the formation of magnetite and to prevent entirely the formation of hematite, or to wipe out any that might have formed. Because the intrusives were large there was a large amount of sulphur available; because of the size of the intrusives, their slow loss of heat, and the absence of much differential contraction, the sulphur followed essentially the same paths as the earlier solutions. Therefore the high-sulphur contact deposits in general, and the pyrrhotite deposits in particular, are associated with large batholithic intrusives.

To sum up, it seems that the tendency for hematite and pyrrhotite to avoid each other is sufficiently well marked to demand an explanation. Whether the explanation here advanced is of any value is another question. It may be that the diagram and the speculations which accompany it are idealized to such a degree as to be altogether out of touch with fact. I believe, however, that the conception of the double variable—variation in depth of ore formation and in depth of origin of the ore solutions—is one that is worthy of some attention.

CONCLUSION.

The attempt has been made to bring out some general rules which are believed to be broadly true, though in special cases exceptions can no doubt be found to them. These are:

1. That there is an antipathy between ferric oxide and the sulphides, most readily visible in contact metamorphic deposits, because in them ferric oxide tends to be most abundant.

2. That this antipathy is best seen in the case of the mineral hematite, which is most abundant in deposits which are sulphur-poor, less abundant in those which are sulphur-rich, and absent from those which contain pyrrhotite.

3. That the time and space relations suggest that hematite does not form in the presence of abundant sulphur, and that if already formed it is destroyed. That is, those ore solutions from which sulphur compounds are deposited have in general a reducing effect on hematite; and hematite, therefore, exerts an oxidizing action on the ore solutions and probably on the sulphur compounds themselves.

The original purpose of this study, as already stated, was to obtain data which would throw light on the origin of the Michigan copper deposits. The conclusion, that the hematite in sulphide deposits has in general played the part of an oxidizing agent, is regarded as offering some confirmation for the hypothesis outlined in the opening paragraphs.

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SEDIMENTARY ANALYSIS OF THE LIMESTONES OF THE CHESTER SERIES.[1]

J. E. LAMAR.

INTRODUCTION.

THE Chester series in Illinois is economically very important since from its sandstones is produced the oil in the Allendale, Sandoval, Carlyle, and Centralia areas, and 90 per cent. of the oil in Lawrence County. At the outcrop the sequence of beds composing the series is well known. It consists of seven sandstone or sandstone and shale formations alternating with eight limestone formations whose names and stratigraphic succession are given in the accompanying figures. However, in the east central part of the State the correlation of the strata with the section at the outcrop is not clearly established. In some cases, also, it is difficult to correlate with much certainty, even in comparatively limited areas. In an endeavor to find means of sub-surface correlation of the members of the Chester series in Illinois, other than by gross lithology and paleontology, the Illinois Geological Survey has instituted a microscopic and sedimentational study of the limestones along the following lines: (1) the amount of residue left after the solution of the carbonates with hydrochloric acid, (2) the size of the particles composing these residues, (3) the heavy minerals contained by the residues and their relative abundance, (4) the texture of the limestones, and (5) the microfossils present. The samples on which these analyses are being made were taken from outcrops in southwestern and south-central Illinois. About 2,000 samples have been collected from known horizons. They were taken bed by bed from carefully measured sections which in almost every case included the contact of the formation being sampled with the over- or underlying formation so that the location of the samples stratigraphically is as accurate as possible.

[1] Courtesy of Chief, Illinois State Geological Survey.

The present paper deals with two sets of analyses for each of the limestone members of the Chester group. The sets of samples chosen have been selected to represent the characteristic phases of these formations as they are known in Union and Johnson counties.

Although the samples studied in this investigation have been taken from outcrops, the comparatively small amount of limestone required makes feasible a similar study of chips from churn drill cuttings or cores. From the results at hand, it is thought that this type of study holds promise of giving additional or unique means of sub-surface correlation for dominantly calcareous rocks whose non-calcareous constituents are chiefly clastics. Highly siliceous calcareous rocks or those containing pyrite, secondary silica and the like have been found to give unsatisfactory results and are thought to be unsuited to the procedure or for the purposes mentioned.

METHOD FOR DETERMINING AMOUNT OF RESIDUE.

Thirty grams of limestone, crushed to pass a 10-mesh sieve, are treated with chemically pure hydrochloric acid until effervescence ceases. The residue is collected on a weighed filter paper, washed, dried, and weighed. From these results the amount of residue is computed. To prepare the residue for sizing it is thoroughly shaken with a small amount of distilled water until any lumps resulting from the drying have disintegrated. If it is extremely tenacious it may be broken up by rubbing with a rubber pestle in a mortar. A small amount of sodium hydroxide solution is commonly used to deflocculate the clay. The residue is sized by allowing it to settle for five minutes in a 15-inch column of water. The material which has not settled contains the clay and silt grades; the settlings are the sand grade. The clay and silt grades are separated by allowing them to stand for five minutes in a 5-inch column of water. The clay grade is siphoned off.[2] The three grade sizes thus produced are finer

[2] The details of this procedure were furnished the author by the Geology Department of the University of Iowa.

than 1/64 mm., 1/64 mm. to 1/32 mm., and over 1/32 mm. The coarsest material is further separated by sieving into grade sizes 1/32 mm. to 1/2 mm., and over 1/2 mm. In this manner four grade sizes are obtained which for convenience of discussion have been called clay, silt, sand, and over-size, respectively.[3] The separation of the residue into the sand and over-size grades is made to differentiate between primary sand grains and such other materials as chert fragments and aggregates of secondary silica.

RESULTS OF ANALYSES FOR AMOUNT AND GRADE SIZES OF RESIDUE.

Fig. 1 shows the average residue and grade sizes for the formations considered in this paper. It is interesting to note that the upper Chester formations have a much higher residue, in general, than the formations of the lower and middle Chester. The average for the upper Chester is about 12 per cent. insoluble in contrast with 8 per cent. for the middle and 8 per cent. for the lower Chester.

In studying the average formational residues, two principal features are considered, (1) the amount of residue, and (2) its distribution into grade sizes. In Fig. 1, the outstanding features shown by the graph are as follows: the Kinkaid is unique with a high residue, a very high clay and very low over-size content. The Golconda and Paint Creek approximate the Kinkaid but the former residues are in general not as high, the clay content lower and the over-size higher. The Clore graphs show a concentration of material into the clay, silt and sand grades with considerable variation between the first and third grades. The grade size graphs in themselves are hardly distinctive, but the graphs taken together with the high residue are not duplicated in the analyses presented. Almost equal amounts of the sand and clay grades seem to be distinctive of the Menard. The Vienna is characterized by high over-size content and considerable variation in the remaining grades. The Glen Dean is the most variable formation

[3] These do not exactly correspond with the sizes as specified in Wentworth's paper: Wentworth, C. K., "A Scale of Grades and Class Terms for Sediments," *Jour. Geol.*, vol. XXX., No. 5. July–Aug., 1922.

of the two sets studied and according to the data at hand apparently has no outstanding features. The Golconda is characterized by a clay bar about two thirds longer than the sand bar and

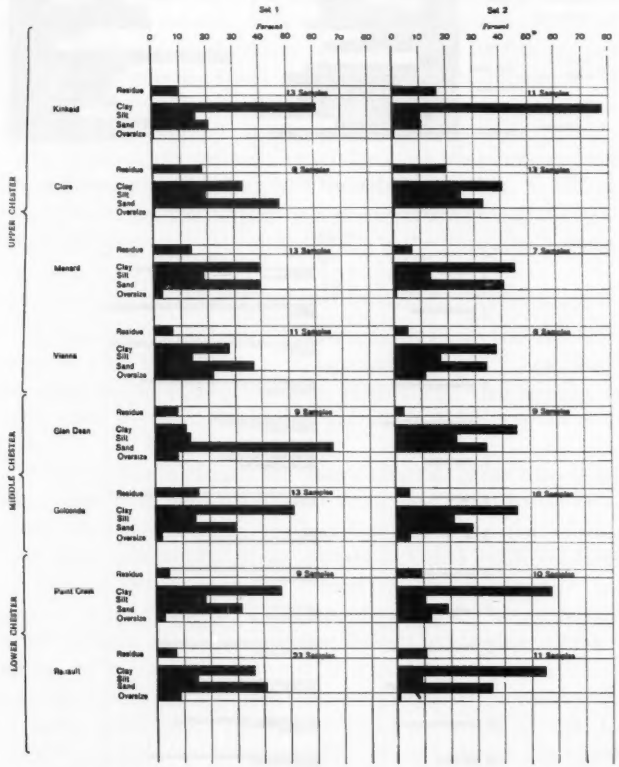

FIG. 1. Average analyses for limestone members of Chester group.

a medium over-size. The Paint Creek has a high clay content, relatively low residue and medium to high over-size. The graphs of the Renault show considerable variation but there is a concentration of the residual material into the sand and clay grades.

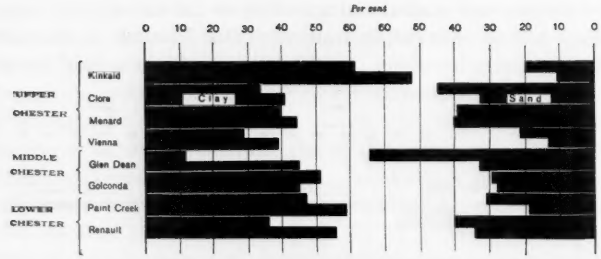

FIG. 2. Relations of clay and sand grades of average analyses.

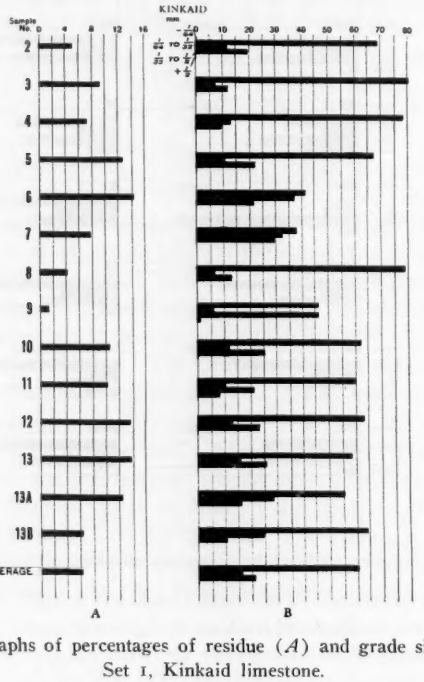

FIG. 3. Graphs of percentages of residue (*A*) and grade sizes (*B*) of Set 1, Kinkaid limestone.

Fig. 2 shows the percentages of the sand and clay grades plotted as units. It is of interest to note that there is commonly a decrease in the clay content with an increase in the sand content and vice versa. Graphs of the silt and clay content show that the silt is relatively constant, while the over-size grade, influenced as it is principally by secondary materials of the limestones such as chert fragments and siliceous replacements, is of interest chiefly as indicating the relative abundance of these materials and seems to bear no important relation to the other grade sizes.

Fig. 3 shows the sedimentary analyses for the samples of the Kinkaid limestone of Set 1 and is included to show the variations in the graphs for the samples of a given formation and the relation of the graphs of individual samples to the formation average.

HEAVY MINERAL STUDIES.

The silt and sand grades from the residues are treated individually with bromoform in a separatory funnel. The heavy minerals are those which sink in bromoform. An attempt is being made to record the relative abundance of the various minerals.

Work to date indicates that heavy minerals other than those which may have been secondarily introduced into Chester limestones are confined chiefly to the limestone below the Vienna. The upper Chester limestones contain in places relatively large amounts of pyrite, in some instances replaced by limonite, but primary heavy minerals are confined principally to occasional small crystals of zircon. In the lower and middle Chester, zircon, rutile, tourmaline, ilmenite, and garnet grains are relatively common in most of the limestones and particularly in the detrital or sandy limestones. The zircons occur commonly as well developed crystals, but many rounded and sub-angular grains are also present. The rutile is commonly found as rounded grains, usually elongate and rod-shaped. The tourmaline occurs in a variety of colors from very pale yellow through brown to almost black. The grains are in the form of crystals with all variations to well-rounded ovoids. The garnets are commonly almost white

or pinkish, more rarely greenish and commonly well-rounded. Tabular flakes of muscovite with rounded edges are also common, but no muscovite was noted in the Paint Creek residues.

A thin section is used in the study of texture and is made from a chip of limestone taken at right angles to the bedding. The texture is recorded according to the classification proposed by Hirschwald [4] and redescribed by Howell.[5]

The outstanding textural feature of the lower and middle Chester limestones is the presence of calcareous sand and oölite. The sand is composed chiefly of well-rounded fragments, probably fossil debris, held together by a calcareous cement, commonly microcrystalline. Many different sorts of oölite grains are present—some with crystalline centers, some with small fragments of fossils as centers, and others without distinct centers but showing radial and concentric structure. However, no particular type of oölite grain has been found restricted to any individual Chester formation.

Oölite grains are rare in the upper Chester. A few were observed but they are not common. Many of the limestones of the upper Chester are composed of fossil debris, but in general the detritus is not so well-rounded as that of the lower and middle Chester and does not so much resemble a sand. The ground mass surrounding the detritus in the upper Chester is in general microcrystalline or cryptocrystalline. The Clore and Kinkaid limestones, in particular, contain beds which are entirely free from fossil material and are cryptocrystalline or microcrystalline in texture. Such beds seem to be principally restricted to the upper Chester.

It is hoped that further work will show that some of the relations of the residues and the grade sizes of the materials composing them will be sufficiently constant to make them of value, at least as confirmational data, for sub-surface correlations with well cuttings, or for surface identification of formations where faulting has caused obscured relationships. Also that the tex-

[4] Hirschwald, "Handbuch der bautechnischen Gesteinsprufung."

[5] Howell, J. V., "Notes on the Pre-Permian Paleozoics of the Wichita Mountain Area," *Bull. Am. Assoc. Pet. Geol.*, vol. VI., No. 5, pp. 413–425, 1922.

tural characteristics, particularly textural details and the distribution and abundance of the heavy minerals, may contribute sufficient additional data to make possible sufficient criteria to recognize from well cuttings stratigraphic horizons in the Chester series.

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ORE DEPOSITION AT PREMIER MINE, B. C.

W. D. BURTON.*

INTRODUCTION.

One of the richest bonanzas in British Columbia, and at the same time one of which so little is generally known of the detailed geological relations, may well merit some slight attention. The record of the Premier Mine since it started serious production in 1921 is well known, the production to date being approximately 615,000 tons of ore mined, yielding approximately 522,000 ounces gold and 13,700,000 ounces silver, with a gross value of about 19 million dollars.

The mine is situated about 150 miles north of Prince Rupert, the western terminal of the Canadian National Railway, and is eleven miles from tide-water at the head of Portland Canal, a natural fiord which penetrates the Coast Range of British Columbia for fifty miles or more.

GEOLOGY.

The general geological features of the deposit and of the surrounding district have lately been described by Schofield and Hanson,[1] but may be briefly recapitulated here, with some additional detailed observations.

Flanking the eastern contact of the great Coast Range batholith, and intruded by it, is a series of volcanics interbedded with and generally overlain by slates and conglomerates, and all regarded by the above writers as Jurassic in age. In the vicinity of the mine, which is three quarters of a mile from the batholith con-

* Subsequent to the receipt of this manuscript, word has been received of the fatal illness and death of Mr. Burton on March 16 at Samne, Peru, where he was employed at that time as geologist for the Northern Peru Mining and Smelting Co.

[1] S. J. Schofield and G. Hanson, "Geology and Ore Deposits of the Salmon River District, B. C.," Mem. 132, Canada Geol. Survey, 1922.

tact, the upper sediments have been removed, and the underlying volcanic series consists of three petrographic members, of total thickness of at least 2,000 feet from the top to lowest observed horizon as follows:

Dense fragmental andesitic tuff Dense near-surface intrusion of andesite	greenstone.
Coarse tuffs, agglomerates and breccias.	

This series strikes roughly parallel with the main batholith contact, N. 40° W., with a local southwesterly dip of 45° toward the granite mass.

The oldest igneous rock is a granodiorite porphyry intrusive into the above series. Schofield and Hanson regard the porphyry as a series of sills injected along the bedding of the tuff, but in the Premier Mine it forms an extremely irregular stockwork in the greenstone, and contains numerous huge irregular inclusions of the latter.

The above rocks have been cut by large diorite or granodiorite dikes from the batholith prior to whose intrusion both volcanics and porphyry were extensively sheared and highly altered. The last phase of igneous activity was the injection of numerous lamprophyre dikes. They have been regarded as postmineral in age, but this view is untenable in the case of the Premier Mine, at least. Here the dikes intersect the mineralized zone in a number of places, and are slightly mineralized near the edges, as well as showing similar alteration effects to those induced in the porphyry and greenstone as a result of the action of mineralizing solutions. Furthermore, hypogene mineralization commonly spreads out both on the hanging wall side and on the footwall side of cross-cutting dikes.

The mineralized veins are of the replacement type and occur in fracture-zones particularly developed along a tuff porphyry contact.

ROCK ALTERATION.

The three rocks occurring in the mine, viz., tuff, igneous greenstone, and porphyry, have been sheared and profoundly altered

by regional processes until the original mineral constituents are almost totally replaced by chlorite and sericite, dominantly, with much calcite and epidote as well.

Superimposed upon this wide-spread alteration is a second and distinctly later process activated by mineralizing solutions ascending along fracture planes in the rocks. The minerals thus formed to distances upward of 100 feet from the vein are pyrite, chlorite, quartz, sericite, apatite and possibly calcite, with chlorite giving way to sericite and quartz, as the vein is approached.

Silicification within 10 or more feet of the vein has usually been intense, the porphyry in particular becoming light green to gray and almost white in color, and microscopically composed of a very fine-grained mass of quartz, sericite, calcite and perhaps a little residual feldspar. Then immediately adjacent to the mineralized vein, microscopic veinlets of coarsely crystallized quartz and adularia, with considerable sericite and an iron-rich chlorite approaching daphnite in composition, cut and replace the silicified rock.

Deposition of vein-pyrite and quartz closely followed the adularia-quartz replacement, and the later sulphides forming the ore body have developed by replacement of all these minerals.

The above succession of events can be followed in both greenstone and porphyry, though the effects are much more pronounced in the latter.

VEINS.

Two main fracture systems, one roughly parallel with the batholith contact (N. 40° W.), and the other at right angles to it, control the locus of ore deposition. Fracturing has been concentrated along the contact between the porphyry stock and the greenstone, and the main ore zone, striking N. 50° E., follows this contact, with a dip of 50° to 75° to the northwest. The northwest ore zone is ill-defined, but where it joins the southwest end of the main ore zone, mineralization has been particularly intense, and the sulphide body is unusually wide due to the porphyry being rendered highly permeable in that locality. With increasing depth porphyry gives way to tuff at the zone intersection, and the sul-

phide body here becomes much narrower and lower in grade, the type of vein changing from an ill-defined replacement of silicified porphyry to a narrow massive sulphide vein apparently more the result of space filling. The porphyry and tuff are very similar mineralogically and chemically, so it would appear that the physical conditions of the tuff were not conducive to extensive replacement. The porphyry is quite brittle and would tend to yield to stress in a multitude of fine cracks, while the tuff would tend more to incipient flow or internal shear, still maintaining its compactness, and so be less permeable to mineralizing solutions.

HYPOGENE DEPOSITION.

The following minerals have been formed by hypogene processes, and are given roughly in the order in which they have crystallized. Those starred may also occur as supergene minerals.

Ore Minerals.	*Gangue Minerals*
Pyrite	Apatite
Sphalerite	Adularia
Galena	Quartz
Tetrahedrite	Chlorite
*Chalcopyrite	Sericite
Electrum	*Calcite
*Argentite	Barite
*Polybasite	Albite
Pyrargyrite	

The texture of the vein-forming minerals in the lower levels, and of the base metal sulphide intergrowths in the upper levels, is, in general, a fine-grained intimate mixture. Banding in the massive pyrite-sphalerite-galena-chalcopyrite ore in the lower workings is quite common. Going upward the ore texture becomes coarser and the vein becomes generally more siliceous, with calcite, barite, and albite, appearing in increasing quantity. Vugs and cavities are of frequent occurrence in the upper zones. Fracturing appears to have occurred repeatedly throughout the process

of vein-formation with the major amount of movement occurring early in the process, after the first replacement of the country rock by adularia, quartz, and pyrite. In the intermediate and upper levels any or all of the minerals post-pyrite in age may occur filling fractures sometimes several inches wide in the vein or in otherwise barren wall-rock.

Base Metal Sulphides.—By far the commonest type of ore, and that formed almost exclusively with depth is one in which pyrite and sphalerite, usually with considerable quartz, are the predominant minerals. Galena is much less abundant, but at times takes part in the sulphide banding, as does chalcopyrite, a still less abundant mineral.

Pyrite, with quartz, is the earliest vein mineral to form, and in but slightly mineralized rock is the only sulphide present. It is universally fractured and corroded as a result of replacement by quartz and later sulphides.

Resin brown sphalerite, practically always containing the familiar chalcopyrite inclusions, is abundant, and where massive, is locally considered to carry more than average gold values. Microscopic examination, however, failed to reveal electrum, the gold-carrier, as especially abundant in the blende, in fact it is much more often associated with galena.

Galena is always coarsely cleavable and replaces pyrite and sphalerite universally. It is often abundant along certain fracture-planes crossing the orebody,—as is tetrahedrite—representing fracture filling in the pyrite-sphalerite ore. Galena, after careful microscopic search, will practically always show a few scattered blebs of included tetrahedrite, as well as an occasional bleb of electrum, both these minerals being considered as belonging to the same general period of mineral formation as the galena. These included grains doubtless account for the gold and silver values carried by the base-metal sulphide ore. The cleavage lines of galena are often curved, as a result of stress after crystallization.

Tetrahedrite.—Tetrahedrite is not found in large quantity below a depth of 650 feet, but above this it locally occurs in massive

form, when it is almost always extensively replaced by supergene polybasite and native silver. The most wide-spread occurrence of tetrahedrite is with galena and often polybasite and electrum as well, replacing sphalerite and the gangue minerals in a manner suggestive of contemporaneous formation (Fig. 1).

FIG. 1. Characteristic association of electrum (white), galena (*G*), tetrahedrite (stippled), and polybasite (*P*) replacing sphalerite (*S*) and calcite (black). × 160.

In general it may be said that a quantitative vertical zoning of tetrahedrite is pronounced, in that it is sparingly disseminated in the massive sulphide ore in depth, but occurs in good quantity with galena and hypogene polybasite nearer the surface, where it also forms massive segregations along cross-fractures cutting the quartzose ore and wall-rock.

Electrum.—Electrum, the pale yellow alloy of gold and silver occurs universally throughout the deposit, and nearly any ore specimen, after careful microscopic search, will reveal its presence. The mineral is more abundant in the upper 500 or 600 feet of the deposit where there has been a departure from the usual mode of intimate admixture of the other hypogene minerals, particularly

where there is much polybasite and tetrahedrite associated with more than the usual amount of galena. Microscopically the characteristic occurrence is as small rounded grains probably forming by replacement of galena or other surrounding minerals, although not demonstrably later.

In several cases polished surfaces of scale-like growths of argentite intergrown with and capped by what is apparently native silver were examined under the microscope, and much of what was thought to be native silver proved to be electrum. At first glance the boundary between native silver and electrum appears gradational, but etching with $FeCl_3$ proves that the boundary is quite sharp, and emphasizes the existence of electrum as a well-defined mineral, not subject to variation in composition when attacked by silver-rich solutions.

Electrum is probably almost entirely responsible for the gold and in ore with high gold assays much of the mineral can be seen with the microscope.

Gold of this type, carrying silver, is rather characteristic of the epithermal vein zone,[2] although the deep yellow purer gold is not at all rare. Bastin and Laney[3] report electrum from the veins at Tonopah, accompanied by galena, polybasite, argentite and pyrargyrite, all of which minerals occur in part at least as hypogene minerals.

Argentite.—Argentite is rather a rare mineral in the deposit, and like pyrargyrite and polybasite has not as yet been observed at depths greater than 500 feet. It has been observed along with galena and electrum and small quantities of the other base-metal sulphides cutting calcite, barite, and quartz in well-defined replacement veinlets. In places an argentite veinlet will give way abruptly to electrum or galena, which minerals will for a space fill the same width of veinlet from wall to wall. Here argentite is not demonstrably later than electrum, although it replaces galena elsewhere in the same specimen. Argentite is practically always veined by native silver.

[2] W. Lindgren, "Mineral Deposits," 1919, p. 476.

[3] E. S. Bastin and F. B. Laney, "Genesis of the Ores at Tonopah, Nev.," Prof. Paper 104, U. S. Geol. Survey, 1918.

In the case mentioned above when discussing electrum, where slickensided porphyry is coated with scale-like growths of argentite, electrum and native silver, with some sphalerite deposited on the same surface, the electrum is embayed and replaced by argentite and argentite is cut and replaced by native silver. It is practically impossible to classify argentite here with native silver as supergene, or with electrum as hypogene. As is so often observed, the fracture was formed as an early process in the hypogene mineralization, so mere fracture-coating is no criterion to be used in determining whether a mineral is hypogene or supergene.

The evidence pointing to hypogene argentite is far from convincing, but the association with electrum and coincidence of vertical range with hypogene polybasite and pyargyrite is suggestive.

Polybasite.—The most spectacular occurrences of massive polybasite, which are always associated with native silver, seem to be supergene, and extend to 650 feet below the surface. The mineral also occurs, however, in two ways, very suggestive of hypogene origin, in neither of which is it determinable without the aid of the microscope.

1. As rounded blebs of smooth outline in galena. In only one or two cases was it possible to be sure that polybasite was replacing galena, and then it was in a manner considered characteristic rather of hypogene replacement than otherwise. Polybasite never occurs as long narrow veinlets replacing galena along the cleavage as is the usal mode of replacement by supergene agencies, exhibited in the case of certain long narrow veinlets of polybasite cutting tetrahedrite, and replacing it around boundaries with other minerals, but polybasite of this order of occurrence is intergrown with galena, tetrahedrite, and electrum (Fig. 1) in a manner suggestive of contemporaneous formation, and is almost conclusively a hypogene intergrowth. There is practically never any native silver present.

2. As brownish (microscopically) masses of polybasite intergrown with pyrargyrite, commonly filling vugs in quartz or replacing calcite and some earlier sulphides which have filled the vugs. Native silver is not present in this case. Evidence leading to the

conclusion that this is a hypogene intergrowth may better be taken up under "pyrargyrite," as it is the most abundant of the two sulpho-salts, and most easily determinable both in polished and in thin section.

On the whole, hypogene polybasite is never present in very large amount, is never found in the lower 200 feet of the mine, but is widely disseminated above this, associated with galena or pyrargyrite.

Pyrargyrite.—As an ore mineral pyrargyrite is of about the same relative importance as polybasite, but as a hypogene mineral it is more abundant, though not so widely disseminated. It occurs generally with very quartzose and calcite-bearing ore with vug-fillings and pyrargyrite replacements as much as an inch in section.

As mentioned above under "polybasite," the two sulphantimonides commonly occur together filling vugs or replacing calcite vug-fillings in quartz; and also replacing vein quartz or calcite and other earlier sulphides in a finely disseminated manner, in exceedingly compact and impervious material. In thin section pyrargyrite (with polybasite) occurs very intimately disseminated in short discontinuous stringers and irregular blebs replacing the fine-grained quartz-adularia-calcite replacement of the wall-rock. The sulpho-salts quite evidently have replaced these gangue minerals in precisely the same manner as have disseminated grains of the base-sulphides, and there is absolutely no justification for considering them as supergene minerals. In similar material pyrargyrite is observed coating minute fracture planes in quartz-pyrite ore, accompanied by tetrahedrite, sphalerite, galena and polybasite; another case of fracture-coating by hypogene mineralizing solutions.

An unusual replacement feature is exhibited by an association of pyrargyrite, galena, and sphalerite (Fig. 2.). Here, as in every other case observed, sphalerite is older than galena and is replaced internally and externally by galena and pyrargyrite respectively, leaving the irregular protecting shell shown. Tetrahedrite may at times take the place of sphalerite in this same structure, and in other cases a complete rim of tetrahedrite will protect

pyrargyrite from replacement by supergene polybasite. This structure has been observed before,[4] but has never been adequately explained. It would be interesting to know whether these mineral rims were of abnormal chemical composition.

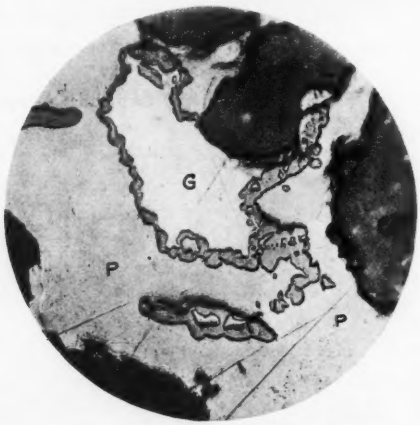

FIG. 2. Sphalerite rim replaced internally by galena and protecting galena (white) from replacement by pyrargyrite (*P*). Quartz (black). × 170.

Summarizing, pyrargyrite is held to be a hypogene mineral in that it occurs in massive compact ore often to great distances from any evident channel of downward circulation, intimately replacing the gangue minerals as do the other earlier sulphides; with the other sulphides it coats minute fracture-planes in quartz-pyrite ore; and it never contains any native silver, which is so abundant in all polybasite formed near channels of downward circulation.

Gangue Minerals.—Apatite, while not strictly a gangue mineral of the ores, yet owes its origin to the same processes. It is quite abundantly disseminated in the altered country rock and charac-

[4] M. E. Hurst, "Rock Alteration and Ore Deposition at Telluride, Colorado," ECON. GEOL., vol. 17, 1922, p. 700.

teristically forms euhedral replacements in the intensely sericitized feldspar phenocrysts of the porphyry.

Adularia seems to have formed with fine-grained quartz as an early replacement of the country rock, and is abundant immediately adjoining the veins, where the porphyry has not entirely lost its identity. Much of the mineral was observed in association with pyrargyrite, polybasite, and sulphide replacement of silicified porphyry.

Rather coarsely crystalline quartz is by far the most abundant gangue mineral, and is practically always present apparently increasing in quantity as the surface is approached. Deposition of vein-quartz ceased early in the process of mineralization and none is observed definitely later than sphalerite.

Calcite is a fairly abundant gangue mineral particularly in the upper part of the deposit, when galena, tetrahedrite, polybasite and electrum have very generally developed by replacement of calcite along the cleavage. Some, though not all of the material tested showed a trace of manganese.

The paragenetic relationship of calcite is pretty well defined, the mineral forming with tetrahedrite and chalcopyrite with depth, but preceding sphalerite in the upper levels.

Barite and albite are very sparingly present in the upper part of the deposit, associated with calcite and quartz.

Chlorite of a deep green color has been observed replacing silicified porphyry with quartz and adularia, and again with pyrargyrite and sericite filling vugs in massive white quartz. It was identified microscopically as being near the iron-aluminium variety—" daphnite."

Sericite almost parallels daphnite in occurrence, with the additional feature that it is often present in the vicinity of veinlets of supergene polybasite replacing tetrahedrite. In such cases it doubtless originated as a hypogene mineral, and supergene replacement of tetrahedrite by polybasite has left the sericite foils remarkably intact.

Summary of Hypogene Effects.—The solutions first emanating from depth along the shear zone were apparently hot alkaline

solutions containing silica, carbon dioxide, phosphorus and sulphur. They penetrated the wall-rocks to considerable distances from the main channels of circulation, reacted chemically with the wall-rock silicates, and deposited certain new minerals as metasomatic replacements of these silicates. The first effects were the formation of apatite, chlorite, and pyrite with considerable fine-grained quartz and some sericite and calcite,—minerals now found to distances of 100 feet or more from the veins. With progressive saturation of the rocks by fresh hypogene solutions, some of the earlier-formed minerals,—particularly chlorite, became unstable and were replaced progressively by larger quantities of sericite and calcite, by adularia and daphnite, and by more coarsely crystalline quartz and large quanties of vein-pyrite.

After this first general stage of replacement, the solutions seem to have become depleted in sulphur, movement and fracturing occurred along the veins, and quartz continued to crystallize. Then calcite was deposited, veining the earlier minerals, and filling vugs in quartz.

As the solutions became depleted in silica and carbon dioxide, sulphides, probably in solution as alkaline sulphides, began to appear and a more or less well-defined series of minerals was deposited as the composition of the solutions successively changed. First sphalerite was deposited in quite a well-defined period; then galena, accompanied or closely followed by a gold-silver alloy (electrum), by chalcopyrite, by tetrahedrite, and even polybasite appears at times to fall in this group, though distinctly later, on the whole. These minerals have formed almost exclusively by replacement of earlier-formed minerals, though fracture-filling has also occurred, particularly in the upper part of the deposit.

The apparent increase in quantity of tetrahedrite and electrum in the upper part of the mineralized zone may be attributable to the greater amount of open space existing higher up and this appears to have dominated the development of tetrahedrite. A contributing factor may well have been a lowering of the temperature of the depositing solutions with increased altitude. The existence of adularia would indicate a depth below the surface not

exceeding say 3,000 feet, and the temperature of up-rising solutions could be expected to fall much more rapidly in such a zone, as the surface was approached, than in a zone traversed 4,000 or 5,000 feet below the surface.

As silver became more plentiful, argentite was deposited, largely by replacement of galena, and still later, as antimony became abundant, polybasite and pyrargyrite were formed, replacing quartz, calcite, and sulphides. The fact that these two sulphantimonides, when hypogene, occur only within 500 feet of the surface, confirms the observation made in the cases of tetrahedrite and electrum that a vertical zoning has occurred, and here likewise it is explained by the assumption of a steep temperature gradient. These minerals are not stable in highly heated alkaline sulphide solutions,[5] but are quite stable at lower temperatures, such as may be assumed to have obtained in the upper part of the deposit. It is also quite possible that the solutions toward the close of the mineralizing epoch when these minerals were deposited, were becoming decidedly cooler than previously, rendering the sulpho-salts stable.

No arsenic was detected in any of the minerals occurring throughout the deposit.

SUPERGENE DEPOSITION.

Fracturing of the hypogene ore has been relatively intense, in many cases such fractures representing reopening of fissures formed early in the process of hypogene mineralization; the topographic relief of the deposit is now great, a drop of 900 feet occurring within half a mile of the mine; and hypogene deposition occurred presumably in late Jurassic or early Cretaceous time. It might, then, be expected that during the Tertiary era descending waters would perform certain changes in the vulnerable hypogene ores, and the following minerals owe their origin to such agents.

[5] L. G. Ravicz, "Experiments in the Enrichment of Silver Ores," ECON. GEOLOGY, vol. 10, 1915, p. 374.

Ore Minerals.	*Gangue Minerals.*
Polybasite	Kaolinite
Chalcopyrite	Limonite
Native silver	Calcite
(Argentite)	
Covellite	

Polybasite.—The occurrence of polybasite as a supergene mineral is confined almost solely to replacement of tetrahedrite which has formed as veinlets—often several inches in width—traversing the base-metal sulphide ore within 650 feet of the surface.

Microscopically, replacement of tetrahedrite commences from long, narrow, and usually straight veinlets representing minute cracks in the tetrahedrite along which the silver-bearing solutions have worked. Another favorite point of attack is around the boundaries of sphalerite and pyrite grains embedded in tetrahedrite. Native silver is nearly always present in distinct veinlets or in irregular rounded masses in the polybasite. Chalcopyrite usually forms as a secondary mineral during the replacement of tetrahedrite by polybasite as will be described below.

Chalcopyrite.—Chalcopyrite has been observed as very small crystals deposited in quartz-lined vugs in hypogene sulphide ore 200 feet below the surface. It has been definitely recognized as a supergene mineral, however, only when occurring as small veinlets and masses in supergene polybasite. Such narrow crooked veinlets often appear much more numerous in the vicinty of polybasite-tetrahedrite boundaries than further away in the massive polybasite, with little or no chalcopyrite present in the tetrahedrite itself. The polybasite always contains some copper, but not so much as the tetrahedrite, so as a result copper would be in excess when silver- and iron-rich solutions transformed tetrahedrite into polybasite, and might well go to form the mineral chalcopyrite.

Native Silver.—Native silver occurs abundantly along planes which can be seen to have been excellent channels for downward circulation, and the mineral as a rule never occurs far from these planes in the dense compact sulphide ore. The lowest occurrence

noted is that with supergene polybasite at 650 feet, lower than the lower limit of hypogene polybasite and pyrargyrite. The mineral occurs practically always in wire form, the wires being found attached to the walls of vugs in quartzose ore, usually alone, but sometimes with small masses of polybasite; or it may occur as thick networks of short curling wires growing out from masses of argentite or polybasite deposited either on faces lined with quartz and calcite crystals or on slickensided faces of the porphyry.

Microscopically it characteristically forms veinlets in supergene polybasite and in tetrahedrite, but never occurs with pyrargyrite or hypogene polybasite.

Argentite.—Argentite may be occasionally, though not always, a supergene mineral. In several cases a conclusion could not be reached as to origin, but the tendency is for it to occur with galena and electrum, though later than these minerals, and always partially replaced by native silver.

Covellite.—Covellite was observed microscopically as fine reticulating replacing veinlets in chalcopyrite contained in pulverulent sulphides from the walls of solution channels, and being limited to such cases, gives good evidence of the small effect of percolating waters in compact unfractured hypogene ore distant more than a few inches from an active visible crack or plane of loose friable sulphides.

Gangue Minerals.—Limonite is quite an abundant mineral coating the walls of the major fractures in the western part of the mine in particular to a depth of 700 feet, but that much of it is a very recent and superficial development is shown by the presence of the mineral in places on the walls of the mine workings.

Kaolinite with calcite was observed in a few cases as an earthy coating on quartz from which the once abundant sulphides had been practically entirely leached, with native silver and polybasite deposited as supergene minerals. No sign of oxidation is apparent here.

Processes of supergene enrichment are accountable for a large part of the silver values of the deposit. The gold values are held to be almost entirely due to hypogene deposition of electrum and

decrease steadily with depth. The decrease, while not so great relatively to that of the silver values, would yet parallel it closely if the superimposed effect of supergene silver enrichment were removed.

GENESIS OF THE ORES.

The view that the mineralizing solutions responsible for this deposit, as well as for several others similarly situated within 2 or 3 miles of the eastern batholithic contact, emanated as the final phase of solidification of the batholith in depth, can hardly be denied, though the deposit as a whole bears very close analogy to certain of the near-surface Tertiary deposits (Tonopah in particular) of the south-central Cordillera.

Southwest of the mine, and near the batholith contact, replacement veinlets of pyrrhotite, with pyrite, galena and zincblende, carrying low values in gold and silver occur in silicified sheared "Premier" porphyry; and at another place near the foot of the Salmon glacier, and within several hundred yards of the contact, chalcopyrite predominates over the other sulphides, with low gold values. These occurrences certainly appear to be closely associated with the batholith as to origin, and the natural inference is that the zone of pyrite galena-zincblende veins found so widely distributed at distances up to 2 or 3 miles from the contact is of similar origin. In fact, a rough zoning is suggested, beginning with the above pyrrhotite veinlets, through chalcopyrite veinlets and those of pyrite, galena, and zincblende, and culminating in the Premier deposit, which, as has been shown, is characterized by development of sulpho-salts in a gangue containing considerable adularia.

The present deposit appears rather anomalous when considering the cover under which it was probably formed, if it is assumed that the surface at the time of mineralization was about the same as that at the end of the granodiorite intrusion. The granite peaks to the west rise to heights of 5,500 to 6,000 feet, or about 3,500 feet above the outcrops, and, adding at least 1,000 feet as cover for the granite, the deposit would have been formed at a minimum depth of 4,500 feet. If doming of the strata had ac-

companied igneous intrusion, the surface in the vicinity of the mine might have been considerably lower than that over the center of the granite mass, but no doming is indicated; indeed, wherever studied, the dips are toward the contact, consequently the above figure is easily justifiable. It is rather improbable that a deposit of the nature of the present one, which shows such a rapid vertical zoning, with minerals characteristic of the near-surface type of vein, could be formed under such deep-seated conditions, and hence erosion must have taken place after intrusion and prior to mineralization.

That intense erosion commenced in other places immediately after uplift and intrusion is proved by C. E. Cairnes[6] in a study of the Coquihalla area to the south, where he places the earliest granodiorite intrusion as upper Jurassic and finds great thicknesses of conglomerates, etc. of lower Cretaceous age, the conglomerates containing abundant plutonic detritus. It is also interesting to note that in this area the mid and upper Cretaceous are characterized by a succession of intrusions varying in composition from diorites to acid granodiorites, and it is to these later intrusions and not to the Jurassic granodiorite correlated with the main Coast Range intrusion, that the gold and silver deposits in that area appear to owe their origin. D. D. Cairnes[7] also noted a similar case of granodiorite pebbles being included in rocks of the Laberge series, Kootenay in age, from the Yukon.

There is in the Salmon River district no evidence of igneous activity since the batholith intrusion, unless we except the diorite and lamprophyre dikes, though it is possible that bodies of later intrusions may lie at no great depths and be responsible for some of the mineralization of the district. This, however, can not be proved, and the only alternative appears to be to consider the possibility of erosion taking place contemporaneously with the crystallization of the batholith in depth, with the top of the igneous mass itself already exposed at the time of ore-deposition along its flanks.

[7] D. D. Cairnes, "Whcaton District, Yukon Territory," Canada Geol. Survey, Mem. 31, 1912.

[6] C. E. Cairnes, "Coquihalla Area, B. C.," Mem. 139, Canada Geol. Survey, 1924.

GENERAL SUMMARY.

1. The rocks containing the ore deposits are a granodiorite feldspar porphyry and an andesitic tuff or near-surface intrusion of andesite, both Jurassic in age. These rocks have all been intensely altered and somewhat sheared by regional metamorphism produced, probably, at the time of the nearby granodiorite batholith intrusion.

2. The further alteration of these rocks in the vicinity of the veins does not seem to have been pronounced. The chief effect has been a silicification of the rock by partial replacement by fine-grained quartz in zones often very wide.

3. The veins have formed chiefly by replacement of the rocks in the vicinity of fracture-zones acting as ore-channels. Formation of the veins may be divided into at least two distinct periods:

(1) Replacement, preferably of the porphyry, by quartz adularia and pyrite, with some sericite and chlorite.

(2) Replacement of these minerals by sphalerite, galena, tetrahedrite, chalcopyrite, electrum, argentite, pyrargyrite, and polybasite, deposited in successive but overlapping periods.

4. The presence of polybasite and pyrargyrite in the upper 500 feet of the vein, as well as the vertical-zoning of tetrahedrite and electrum, confirms the evidence of adularia pointing to formation of the vein by moderately cool solutions at relatively shallow depths.

5. Considerable supergene enrichment has taken place in the upper 650 feet in the vicinity of fractures acting as channels of downward circulation, with deposition of native silver and polybasite as ore minerals.

6. The increased gold values near the surface are held to be due to the vertical zoning of primary gold, probably as electrum, rather than to supergene gold enrichment.

The foregoing conclusions are the results of the writer's field study of the deposit during one and one-half years while in the employ of the Premier Gold Mining Company, supplemented by several months detailed laboratory work on personally selected

specimens of the ores. Acknowledgment is due the Premier Gold Mining Company for their coöperation in making this report possible; to A. H. Means, Mining Geologist, for many ideas on the geology of the mine, and to Waldemar Lindgren for many very helpful suggestions during the progress of laboratory work and preparation of this paper.

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MASS. INST. TECHNOLOGY,
CAMBRIDGE, MASS.

EDITORIAL

THE PUBLISHING OF GEOLOGICAL INFORMATION

In geology, as in most other branches of science, the growth of literature is attaining proportions that make it extremely difficult, even for those who have access to a well-equipped library, to keep reasonably in touch with developments. This growth is hardly in itself any cause for lament: few papers only are published that had better finished in the waste-paper basket, and the increasing call for more facts concerning practical experience in applied mining geology, for instance, gives evidence that the supply in this branch at least, does not meet the demand. Yet nobody can read and remember, or make notes on, every single published fact that is of interest to his own work, much less keep up to date in the science as a whole.

As a reader and writer of geological reports and papers I have noted certain truths that seem rather obvious, but appear not to be sufficiently realized. It has occurred to me, then, that a brief survey might be of some use.

When a geologist has something new to tell his colleagues, one of the very first questions that arise, or at least ought to arise, is: *where* to publish? The choice is often very limited, but the question ought always to be raised. For persons connected with a certain institute, the publications of that institute will always be nearest at hand. But it may happen that not all papers are suitable, thus, brief contributions to actual scientific discussions are seldom published in the series of government geological surveys. In such cases the practice, adopted by many such surveys, of allowing the officials a certain freedom of publishing in various scientific periodicals, is highly commendable. Many other considerations may influence the choice: the crowding in certain journals means a long delay in publishing, and may make the author prefer to try another opening; maps and other illustrations

make one periodical better than another of a smaller size, etc. However, one of the first principles ought to be to choose that medium of publication which will most effectively reach the public for which the paper is intended. Thus, if possible, mining geology ought not to be published in the annals of learned societies, perhaps sandwiched between folk-lore and tropical fishes. Undeniably, many valuable publication series are of this type, for administrative or other purposes, as to serve as exchange material for the library of a society or a museum. The unavoidable drawback of the mixed contents can be largely counterbalanced by a generous distribution by exchange or in the form of reprints. Yet on the whole, publications of a more homogeneous character are more sure to reach a specialist, and scientists as such are all of them specialists, nowadays. The ties between the various branches of science, and the broader scientific education are probably better served by journals of the types represented by *Science* and *Nature* than by the crowding of specialized information within the covers of a single periodical. Exceptions there occur, to be sure, such as the *American Journal of Science,* which is of a special type with rather short papers within certain scientific realms and much space given over to the group mineralogy and geology.

Another question concerns the language to be chosen. To those who have for their mother tongue English, or another of the "great" languages, this question does not exist at all, but to others it is of paramount importance. Many factors have to be considered. As a general rule it may be stated that one of the more widely spread languages must be chosen as soon as an appreciable percentage of those who may be interested in the report do not understand the writer's native tongue. This holds true of mineralogy in general, even if the paper may treat only a detail that is in itself rather trivial. Papers on regional geology, on the other hand, are often of interest chiefly to those working in neighboring regions. This is particularly true of short contributions to actual discussions, so long as no exhaustive treatment of the whole problem is intended. Yet many works on

regional geology must absolutely be classed among those which ought to be presented in a form that can be understood by every geologist. A report on an area of igneous rocks, for instance, that illustrates some important features of magmatic differentiation, will certainly interest petrologists far away from the author's own country, and it becomes his duty to see that his observations reach them.

Reports on mining geology present a particular problem. In them, the demands of the local mining industry are generally to be satisfied in the first instance. This circumstance mostly calls for a description in the native language. It is true, at least for my own country, that a reader sufficiently educated to study with profit a geological report on a mining property will also generally be able to understand it if written in English, for instance. But it is not to be counted upon that he will read it quite so fluently, and it will always be difficult in some degree to recognize instantly otherwise familiar terms when replaced by their counterparts in a foreign tongue. One therefore runs the risk of scaring away just those for whose benefit the study has been in the first hand undertaken and the results published. It may also be surmised that few readers in distant countries will be so interested in the report as to study detailed descriptions of features of essentially a local interest. What they want, and have a right to claim in the name of scientific coöperation, is a concise presentation of such facts as are of a more general interest, and these can mostly be satisfactorily recorded in a summary in a foreign language. Only in exceptional cases, when describing deposits of particularly great interest, will it be advisable to lay all the observations recorded before the eyes of the international geological public.

It must be emphasized that these principles lay a considerable burden upon the scientists of several nations. They mean, in most cases, a distinctly increased cost of publishing. Furthermore, the scientist has to make himself familiar with the exact meaning of every foreign technical term to be used, for this can-

not be entrusted to a translator with only a linguistic training, or the results may be terrific.

I have dwelt so long on this question because I have got the impression that its importance is underrated by those who have to face it, while the difficulties they meet are perhaps not always realized by those who because of their nationality are exempted from it.

As to the form in which a scientific description or idea is to be presented, it is unnecessary to emphasize the fundamental importance of a clear and concise style. In reports of some length, it is a welcome feature if there is given, by way of introduction, a summary of contents. This is done in many cases, and serves a twofold purpose: a reader looking for information on a certain subject will generally be able to judge whether to expect it or not, and one who intends a thorough study will be able, from the outset, to weigh each fact that is presented, and to understand its place in the author's chain of evidence. A summary at the end of the report will, in many cases, serve the first purpose just as well, but is generally not put in a form that makes it useful in the last mentioned sense.

When studying a description of a mining district or similar unit, it is convenient if there are reproduced some photographs showing the general character of the landscape. They give an aid to imagination, and make us see the country with the author as a guide in the field, rather than from his writing-desk. Illustrations of all kinds are apt to catch the attention readily when one looks over a paper to see if there is something particularly interesting in it. They are therefore a great aid to everybody who attempts to keep in touch with scientific developments, but is forced to pick out for reading the things most important to him, and leave the rest. It is even a very decided advantage if a journal is delivered with the pages cut!

Except perhaps when an author has had his first scientific paper published, one too often encounters a tendency to regard the author's work as finished when the proof sheets are corrected. When publishing in a series that is widely distributed, this atti-

tude is pardonable, as the paper will soon reach the majority of those who may profit by reading it. Otherwise, it is the author's plain duty to send out reprints to as many as possible, and particularly to see that the various periodicals that give reviews of recent publications are supplied. It is probable that the majority of geologists more than fulfil this demand, but there are always some who are too ready to underrate the value that their scientific production may have to others.

The value of reviews is clear to everybody, I think, but a very great importance must also be attached to surveys of recent progress within certain fields. The "*Fortschritte der Mineralogie*, etc." is a case in point. This series has done much to reduce the trouble for the consumer of scientific literature in keeping up with the pace of production.

PER GEIJER.

DISCUSSION
AND
INFORMAL COMMUNICATIONS

THE FUNCTION OF STATE GEOLOGICAL SURVEYS.

Sir: Merrill's " State Geological and Natural History Surveys " shows that 35 States established surveys between 1823 and 1874 and that all but 6 of the first surveys established in each State were authorized to examine the geology and mineral resources. Of these six, three were described by legislative enactment simply as geological surveys, one as a mineralogical survey, one as a geological and agricultural survey, and one as a survey of swamp lands. It is evident that the primary function of State Geological Surveys is to aid in the development of mineral resources.

A recent editorial in this journal by DeGolyer [1] has discussed the rise and fall of State Surveys, has emphasized the importance of the personal equation between the directors and the executive and legislative branches of State Governments, and has pleaded for coöperation on the part of professional engineers and geologists within the State in order to enable economic results to be obtained by means of reports of technically trained men on different phases of the mineral industry.

The activities of State Surveys vary with appropriations, local conditions, both geological and political, and the interests of those most closely concerned, usually the Governor and Director. All these Surveys are concerned primarily with assisting the development of natural resources. Many of them conduct purely scientific research in conjunction with economic work and the science of geology progresses by this means.

Are not State Surveys failing to appreciate another opportunity

[1] ECONOMIC GEOLOGY, vol. 20, No. 4, 1925, p. 376.

which must become of increasing importance as time goes on—educational possibilities? Mineral resources are controlled to an ever increasing extent by companies who have capital to exploit them and to explore for more. The land owner is no longer the operator; his interest is in bonuses and royalties. Assistance of State Surveys in the form of individual reports and publications regarding mineral development is of less importance to large companies than to individual operators and therefore is of less direct value to citizens than heretofore.

Geology was formerly considered a branch of natural history and was taught and indorsed as such. The age of specialization has rendered the study of natural history under this title extinct and has subdued the interest of the public in rocks and minerals and an appreciation of the story which they tell.

State Surveys can disseminate general knowledge in comprehensive form to the citizens of the States. They can publish reports of limited areas, usually counties, which are available to the students in secondary schools, written for the purpose of teaching the student something about the composition of the earth and the rocks in the particular area where he resides. Illustrations of local features, such as waterfalls, quarries, and gravel pits would serve to stimulate the interest of teachers in cities to take their classes into the country and describe the surface of the earth as well as the living objects upon this surface. Reports have more permanent value than lectures or radio talks, but the latter are a desirable adjunct.

Popularization of a science does not involve lowering of scientific standards, nor an increase in the number of students aspiring to professional or commercial work in science. It enables more people to have an appreciation of the world on which they live. State Survey reports which would create a demand in secondary schools would supplement, not replace the present type of publications and might assist scientific research by ultimately appealing to the legislators, few of whom can understand the specialized scientific language of our geological reports.

Many States have already issued county reports, as well as

bulletins describing the geology of the State, topographic maps, and colored geological maps. The demand for such publications, and especially for bulletins on the general geology, must have been gratifying in many instances because when new editions are not printed the supply is exhausted. State Surveys could increase the distribution of these publications by having colored maps mounted permanently in schools with an insert advertising reports which could be made intelligible to students by their teachers and which would not be "out of print" the year of publication. These maps could be placed above collections of rock specimens and minerals distributed free to all high schools.

SIDNEY POWERS.

TULSA, OKLA.

FORMATION OF PORCUPINE QUARTZ VEINS.

Sir: In his discussion (ECON. GEOL., Jan.–Feb., '26) of my article on the Porcupine veins (ECON. GEOL., Nov., '25) Mr. Spurr is not correct in writing that I conclude that "the quartz has been entirely deposited by substitution for original wall rock." I wrote (page 663):

> Yet the obvious control on the disposition of the veins, by the joints, fissility, schistosity and shearing shown in the figures, shows that the veins followed fissures and therefore that fissure filling played a part. The only difference of opinion that can validly exist, is in the relative importance of fissure filling and other modes of formation. Detailed study leads to the conclusion that there has been filling of numerous narrow partings, such as the joints, fissility, schistosity and sheared surfaces of Figs. 1 to 4 but that the present volumes of vein material must have been developed in large part by modification of the vein fissures during the mechanism of vein formation.

On page 668 I stated:

> As would be expected where fissure filling and replacement were both operating, some vein-rock contacts are sharp while others are vague.

And in conclusion:

This study leads to the conclusion that the Porcupine quartz veins have been formed by the insinuating penetration of numerous tight or very narrow fissures, and replacement of the contiguous rock.

Clearly, my conclusion is that the veins have been formed by a combination of fissure filling and replacement, not entirely by substitution of original wall rock, as Mr. Spurr stated.

Fissure filling is obvious on both a small and large scale. Under the microscope quartz veinlets can be traced along fissures. In some instances a portion of a fissure may be filled and a portion unfilled, giving clear evidence that the quartz veinlet followed a fissure. On a larger scale quartz veinlets can be traced along joints and sheared surfaces. On a still larger scale a quartz vein may follow and lie against a pronounced "shear plane." Some veins, as for instance the once productive Porcupine Crown vein, occupy a strongly fissured zone, (a so-called "shear-zone") giving the vein structural characteristics which miners usually associate with a "true fissure vein."

But in most instances, one must draw the inference that the quartz depositing solutions followed fissures that were tight or very narrow. The best evidence for this is the appearance of these fissures as now visible in the mines. Where traceable they are invariably tight or narrow. It might be argued that they gapped open when vein forming solutions entered and those that were not filled have subsequently closed. Or it might be supposed that the open fissures were all filled and only the tight or very narrow ones, now unfilled and therefore traceable, remain today. Both suppositions are possible but they have no evidence to support them, as far as I know. On the other hand, the geologic history of the rocks argues against these assumptions. The fissures that controlled the course of the veins are typical tight or close-walled types. They are schistose and fissile partings, compression joints, and sheared surfaces of various degrees of magnitude. There is good evidence that these fissures originated in a deep-seated zone, through the agency of compressive stress which tightly compressed the rocks, and the relief from this stress manifested itself in a slipping of the rocks along numerous sur-

faces of differential movement, under conditions that make it difficult to conceive, not to say, prove, the formation of gapping fissures. Vein formation took place in a deep-seated environment with no indicated break between fissure formation and vein formation that might account for a widening of these compression-formed fissures by raising them into a more shallow zone, or in other ways. Since vein formation, geologic processes have worked to denude the overburden from the veins and whatever change in the degree of openings might have occurred, should have been in the direction of widening rather than tightening.

But no matter how narrow each individual fissure may have been, the aggregate volume of quartz, emplaced by fissure filling, in some instances may be an important part of the whole. Some lode exposures show a network of narrow veins and veinlets, illustrating conditions where fissure filling undoubtedly was responsible for a considerable proportion of the emplaced quartz. It is conceivable that if the fissures were numerous enough and closely enough spaced, even though very narrow or tight, quartz veinlets produced by fissure filling alone, could form a quartz lode in which the proportion of quartz was greatly in excess of the rock within the margins of the lode.

In my article I pointed out that it is impossible to account for all the quartz by a process of filling without modification of the fissures, either mechanically or chemically. In many exposures of large masses of quartz, evidence of the original controlling fissures has been obliterated, or the fissures have been so modified as to make their original outlines impossible to trace. Conclusive proof of mechanical or chemical modification during the process of quartz deposition is found in the occurrence of numerous inclusions of country rock, completely isolated by vein substance, as an island is isolated by the sea. This isolation has either been accomplished by mechanical or chemical means, or both. Since I fail to find evidence of the dislocation or contraction of wall rock inclusions or of country rock between veins, and do find evidence of replacement, and since, under the conditions, evidence of dislocation or contraction, or both, would have been

inevitable if it had occurred on any large scale, I discard the theory that the veins have grown by the mechanical distension of their walls, and conclude that replacement accounts for the phenomena.

Mr. Spurr's statement therefore should be amended to read as follows:

"The real and perhaps important point of difference between my views and Mr. Dougherty's is his conclusion that the quartz has been deposited by a combination of fissure filling and replacement, he failing to find evidence of the mechanical distension of fissures, concurrently with injection or crystallization; while I believe that the major mode of intrusion was filling spaces which the invading ore solution or ore magma made for itself, by virtue of its telluric pressure."

Undoubtedly the difference in these conceptions is important. If the ore solutions had the power to distend the walls of invaded fissures, or, as Mr. Spurr literally says, to actually make spaces for themselves by parting and thrusting aside the rock in their path, we have the picture of an overpowering, rending force, less guided by preëxistent structure of the invaded rocks, than by the fury of its own attack. Manifestly, pressure relations would be very important factors in determining the emplacement of the quartz masses, and possibly the localization of the larger masses, with its paramount interest to the miner. On the other hand, if the ore solutions could only follow paths already determined for them by the structure of the invaded rocks, preferentially penetrating the more open portions of the rocks, and dissolving the rock along the walls of the penetrated fissures, with little or no mechanical modification of the configuration of the invaded fissures; then preëxistent structure and the degree of dissolution are the important factors influencing the localization, structure, disposition and size of the quartz masses. A comprehensive series of consequences from both the purely scientific and utilitarian points of view follow upon these conceptions, but a discussion cannot be attempted here.

I certainly agree with Mr. Spurr that the phenomena of dike

intrusion are puzzling and do not understand why he should conclude that I imagine any rule applies to these phenomena. The implication would appear to be that I imagine the phenomena of dike intrusion to consist invariably of a thrusting aside of the invaded rock. Mr. Spurr summarizes some opinions of various geologists to show that replacement is considered to have played a part in the mechanism of igneous intrusion. Not only am I aware of these opinions, but I agree from a study of the recorded observations of others and my own observations, that in many cases the evidence is very strong indeed that replacement has had a part in the phenomena of igneous intrusion. In my article I do not argue that dike intrusion and quartz vein emplacement may not be closely related processes, but merely that a combination of fissure filling and replacement are the dominant modes of formation of the quartz veins. I submit that some or many or all dikes, and some or many or all deep-seated quartz veins, may have been emplaced by essentially the same mechanism and that neither these dikes nor these quartz veins may have thrust aside the rock.

Mr. Spurr says, "It would indeed seem to the thoughtful student that the walls of intrusive masses . . . should show the disturbing effect of having been pushed back." Of this one may say that they should, under certain conditions, if they actually have been pushed back; and should not if they have not been pushed back. If an igneous body enters a fissure it may fill the fissure without any mechanical or chemical modification of the walls of the fissure; it may dissolve the walls of the fissure to variable degrees; or fill the fissure as the latter widens through stress not directly connected with the pressure of the igneous body; or the igneous body may both widen and fill the fissure. The thoughtful student must consider all these contingencies and other possibilities that may present themselves to him. If he does so he need not presuppose the existence of the disturbing effect on the walls of the intrusive body. Even in the case of a widening of the fissure by the pressure of the fluid or crystallizing magma it is conceivable that no such evidence may appear.

The point of my discussion on the Porcupine veins is that there is no evidence of mechanical disturbance to any important degree, and that, under the conditions, it appears inevitable that such evidence would be present if it were a process of major importance. In other words it is necessary to show not only that the evidence is lacking, but that it would be present, should be present, because the conditions were such as to make its expression inevitable. Mr. Spurr, and other proponents of forcible disruption of fissure walls at Porcupine, can refute my conclusions by showing either that I missed the evidence or that it is not necessary to conclude that dislocation or contraction of country rock should have occurred, or if it did occur that its effects would now be observable. Perhaps in some mysterious way the walls of fissures have been pressed back and this fact has failed to record itself. Anyone can assume such a mystery, but without evidence it must be frankly admitted that this is pure assumption.

My conclusions should not be construed to mean that I do not recognize the possibility of pressure upon the walls of the invaded fissures accompanying injection or crystallization, and replacement. I consider it very probable that pressure was an essential partner of replacement. But of course it does not follow that pressure would express itself by pressing back the walls, rather than, as I conclude, by promoting penetration and replacement.

Advocates of the theory that quartz veins of deep-seated origin disrupt the invaded rock by their own pressure have pointed out some instances where the country rock has been distorted along the walls of veins. In every instance of wall rock distortion thorough consideration should be given to the possibility that such distortion is referable to earth movements of pre or post or intervein origin, before the critical reader can be expected to accept the conclusion that pressure due to vein growth is really responsible. At Porcupine the lodes sometimes lie in contorted schist, following or cutting across the contortions, as in Fig. 3 of my article. Such relations might be interpreted by some observers as a pressure effect of the veins, but in every exposure I have seen the inference is clear or strong, that the schist contortion was

independent of vein growth and referable to earth movements. In most cases it is clear that the contortions were present before vein solutions entered.

I use the term "insinuating penetration" to describe the apparent mechanism of injection of quartz depositing solutions, because of the obvious capacity of these solutions to enter numerous avenues, by way of devious paths, without, as I conclude, any important mechanical disturbance of the invaded rocks. It seems as though the solutions were unremitting in their effort to seek out, and penetrate into, the more open and therefore more penetrable portions of the rocks. This mechanism is just as truly an "intrusive" phenomenon as is a violent one. Viscosity of the fluid body, ability to support and transport solid masses, and power to rend and thrust aside rock masses, are not necessary characteristics of the products of magmation. One may subscribe to the belief that quartz veins of deep-seated origin are intrusive mineral bodies, a phase of magmation, and even that they were emplaced by a process closely similar to the mechanism of dike intrusion, without believing that the vein depositing solutions necessarily possessed the characteristics mentioned. In brief, that is my position as far as the Porcupine quartz veins are concerned.

Furthermore, in regard to the nature of the Porcupine ore depositing solutions, one may imagine a "magma-like" character and recognize the vigorous activity of volatile agents, among them water. It is impossible to ignore the agency of water when one notes the abundant water-containing minerals, sericite and chlorite, formed by ore forming agencies. These minerals were also present in the invaded schists so the work of the water present in the rocks before they were invaded by ore forming solutions, must be considered. Fluid inclusions in quartz are common. Sulphides, especially pyrite, were deposited in abundance, much in a disseminated state. Carbonates have been deposited on a large scale. In places tourmaline is abundant. We need not hold to the picture of a geyser-like body surging and

soaking through the rocks, but we must, at least, recognize the probability of a highly fluid body.

ELLSWORTH Y. DOUGHERTY.

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CRYSTALLIZATION TEMPERATURE OF VEINS NEAR THE SURFACE.

Sir: In your recent issue for March–April, Mr. H. C. Boydell reviews a certain feature of my paper on "The Camp Bird Compound Veindike," *i.e.*, the observed occurrence of the main ore horizon in andesite breccia, immediately beneath an overlying andesite flow. Instead of the hypothesis which I suggested to explain the occurrence he suggests another: essentially that of chemical reactions, back and forth, between connate water (which he assumes to have occupied the pores of the breccia) and the ore solution or ore magma which filled the vein fissure.

As for my own hypothesis, I regard it as such and believe it is open to debate. But as to Mr. Boydell's substitute, it must, I think, be rejected; and for many reasons, practical and theoretical. As a decisive practical objection, the wall rock of the barren vein below the ore horizon is of the same porous breccia as that of the wall rock of the main ore horizon. Theoretical objections are multitudinous. Mr. Boydell has constructed a structure of assumption upon assumption, nearly all of which are open to doubt or disbelief or disproving. To take these up *seriatim* would involve much space and unprofitable argumentation. One particular point may be singled out, however, since it is a common false assumption. Quoting my estimates that at the time of the deposition of the Camp Bird vein, "the top of the ore may have been 2,000 ft. or more below the surface," Mr. Boydell at once puts forth as a conclusive consequence that "The Camp Bird vein belongs to the class of shallow zone deposits which Lindgren regards as having been formed at depths which would include that supposed by Mr. Spurr for the Camp Bird and at temperatures ranging from 50 to 150 deg." This may be according to Lind-

gren, but it is contrary to nature; it is indeed difficult to conceive how the idea arose, that in centers of active vulcanism, where ore injection was in many cases preceded and followed by lava eruptions, the temperatures did not exceed 150 degrees down to a depth of several thousand feet. The idea seems to have been based on the increment of heat in cold rocks; and to have antedated the realization that ores are part of the magmatic sequence; that they have been injected in many cases directly after the initial consolidation of the host wall rock; and have been directly followed, in many cases, by lava injections, in some instances along the vein fissures. The reasoning involved would apply to these dikes as well as to the ores, and would conclude that since they formed in the shallow zone of the crust, only a few thousand feet or less deep, these dikes crystallized at from 50 to 150 degrees C. And if it applied to dikes, to push further the *reductio ad absurdum*, it would apply to the crystallization of larger lava intrusions and flows. As a matter of fact, it has been so applied in some cases; and logically, if the initial error concerning temperature of ore crystallization is accepted. From the manuscript of a competent professional geologist, submitted for publication, I cite as an example, this extract:

> . . . the change in mineralization of the veins corresponds with the temperature of deposition as evidenced by the character of the nearby genetically connected igneous rocks, be they granites solidifying under high temperature and pressure conditions or porphyries congealing at the lower temperatures of moderate depths.

But observations on the lavas at Hawaii by the Geophysical Laboratory, Washington, D. C., indicate that lava temperatures may be greatest at and near the surface, due to exothermic reactions among gases escaping with relief of pressure; and it has long been accepted that granite in depth consolidates at a lower temperature than rhyolite at the surface, due to the escape from the magma, at the surface, of the gases which under pressure held the magma fluid in depth. The freshly consolidated magma near the surface, then, will be as hot as or hotter than the freshly

consolidated magma in depth; and that ore injection in many cases occurs in freshly consolidated magmas, filling the first cracks and rifts, I have shown to be true, as I may be permitted to illustrate by a quotation:

> I therefore wish, connecting up earlier statements and principles laid down, to propose as a fact that, in general, metalliferous veins are among the first phenomena immediately succeeding the intrusion and consolidation of an igneous rock; that they typically occupy the first cracks and slight rifts formed by the adjustments due to the cooling magma; that their formation is effected in a very brief epoch of geological time; that, thereafter, the adjustment of the rocks (due to further movement either up or down, of the underlying magma, to shrinkage on consolidation of the intrusive and also the contraction of the intruded rocks due to gradual loss of acquired heat) produces typically faults of all degrees of magnitude, which will not be filled by veins unless there is another igeneous surgence or invasion, and, indeed, another ore-magma surgence or invasion.[1]

[1] "The Ore Magmas," p. 347.

J. E. SPURR

NEW YORK CITY.

REVIEWS

Geology Applied to Mining. 2d Ed. By J. E. Spurr. xxxii + 361 pp. 124 figs. McGraw-Hill Book Co., N. Y., 1926. Price $3.00.

The first edition of "Geology Applied to Mining" is so well known to all students of economic geology that it is unnecessary to describe the purpose for which it was intended. That it served its purpose is evidenced by its large sale. In the 22 years that have passed since the volume was first offered to the public a great advance has been made in some of the conceptions relating to ore deposition. Many of the older notions have been greatly modified and many new theories, founded on more accurate observations, have been invented. The new edition is a new book. The question and answer method of presentation employed in the first edition has been abandoned in the new edition and the text is therefore more compact and the volume more readable.

The new volume is divided into seven chapters, of which the first three deal with the characteristics of sedimentary and igneous rocks, their methods of occurrence and their deformations. Chapter IV discusses the deep seated concentration of metals, Chapter V, their concentration at and near the surface, Chapter VI, ore-deposits and geologic periods, and Chapter VII, the control of ore-deposition exercised by faults, fissures and folds.

Nearly all phases of ore-deposition are treated briefly, mainly by bald statements of what the author regards as facts without much argument as to the correctness of his interpretations. But each statement is fortified by illustrations that seem to confirm it. Perhaps to the reader it will appear that no other views than the author's are possible, since no alternatives are discussed. The pegmatite magmas are emphasized as the vehicles through which ore-deposits have been accumulated. This is justifiable, however, if the book is to be "regarded as introductory to an advanced and quite different style of book, 'The Ore Magmas.'"

The volume is comprehensive. It touches many subjects and summarizes many facts, but it explains no processes. It furnishes an excellent epitome of the way in which ore-deposits occur and suggests the causes of their occurrences, but it makes no attempt to satisfy the reader's curiosity as to the exact nature of the operations that have brought about the results. The book is excellent for the general reader and the practical engineer, since it furnishes him a fine account of the present state of the

science it discusses, but as a text-book for college classes it will not serve so well, since it does not deal in sufficient detail with the theory of ore-accumulations, and the processes concerned. Magmatic segregation, secondary enrichment, contact deposition are referred to so casually that the student would not gain a satisfactory conception of their importance as ore-makers unless his attention were called to them by lectures or by supplementary reading. As a collateral text—a book to be read in addition to the more formal text—the volume will find a place. It will be welcomed by the student preparing for examinations because of its comprehensive summarizing of the field. Many instructors will object to the use of the book as a text because of the strong personal flavor it exudes. They will regard it as propaganda in favor of the author's views, rather than a fair statement of the current views held by the majority of economic geologists.

The book is interesting and suggestive. It is modern and instructive. It is an excellent summary of facts and furnishes a good birds-eye view of the subjects it discusses. It is rather a note-book than a reference book, and as such is a valuable aid to the college student and to the practical engineer who wishes to keep abreast of the recent tendency in the thoughts of those who are busy with the study of ore-deposits. It should be in the library of every economic geologist.

W. S. BAYLEY.

Die Natasmine in Südwest, Afrika, eine pegmatisch-pneumatolytisch-hydrothermale Uebergangslagerstätte mit Scheelit, Molybdänglanz, Kupfererzen und Gold. By E. REUNING. Neues Jahrbuch f. Min. Geol. u. Pal., Beilage Bd. 52, Abt. A., 1925, pp. 193–264.

There are three reasons for reviewing this paper: (1) It deals with a little known, but probably economically important, district in Southwest Africa; (2) the deposit presents a transition phase between a pegmatitic-pneumatolytic and a hydrothermal type; (3) the article shows what can be done in the way of maps and beautiful illustrations to make a paper complete.

The Natas mine is situated 140 miles east of Swakopmund, in the Kuisib Mountains. The rocks consist chiefly of schists and quartzites dipping northerly at angles usually less than 60 degrees. In the quartzites there are thin but persistent limestone layers or horizon markers, also amphibolite "beds," some of them of igneous origin. Mica granite, partly metamorphosed, intrudes the schists and quartzites. At the Natas mine these granites have domed up the older rocks in an anticline. There is evidence of some magmatic stoping with the production of injection gneiss and schist.

Penetrating the schists and quartzites are numerous pegmatitic veins up to 2 meters in width. They follow no particular system of fractures. The main pegmatite vein has a proved length of 80 meters. Besides feldspar, mica, and quartz, there are found scheelite crystals as large as a man's fist, grains of chalcocite, bornite and chalcopyrite as large as hazelnuts, and some hematite, tourmaline and apatite. The most important mineral is scheelite. The primary copper minerals show this paragenesis: chalcopyrite, bornite, lamellar chalcocite. In the bornite and rarely in the chalcocite (but then only near the contact with bornite) there are found several products of segregation from solid solution of the bornite, "Entmischungserze," to which the formulas $Cu_xFe_2S_{\frac{x}{2}+3}$ may be assigned. Chalcopyrite also occurs as "Entmischungserz" as lath-shaped and drop-like particles in bornite. In the zone of secondary enrichment which is shallow (about 10 meters) supergene chalcocite, some native gold, copper carbonates and silicates, cuprite, covellite, and decomposition products of scheelite are found. The enrichment of gold reaches to a depth of only about 3 meters. Such shallowness seems to be a fairly general feature for northern Southwest Africa. Scheelite locally may fill pockets in the pegmatites and make up one third of the vein. Calcite older than the tourmaline is found in some pegmatites. Other calcite-pegmatite veins are sericitized and carry molybdenite in economically important amounts with copper minerals of secondary importance. Scheelite is almost entirely absent in these veins.

A number of quartz veins are intimately associated with the pegmatites. They contain a little feldspar, mica, and scheelite. Copper is more important in them than tungsten. In these veins chalcocite decreases with depth while bornite and chalcopyrite correspondingly increase. The quartz veins are more numerous in the granite itself than in the schists and quartzites. In those in the granite scheelite is practically absent, while gold is added to the copper minerals. Superimposed upon this earlier mineralization in some pegmatites and quartz veins is magnetite and specular hematite replacing feldspars and micas. A period of sericitization was contemporaneous or followed these iron oxides.

At the present time the scheelite and molybdenite deposits are not minable, although they were before the end of the war. The copper and gold, however, are not concentrated enough to be ores except as by-products of the other metals.

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The Geology of the Island of Trinidad, B. W. I. By GERALD A. WARING. With notes on the paleontology by G. D. HARRIS. Johns Hopkins University, Studies in Geology, No. 7. Baltimore, 1926. 170 pp., figs., maps and 20 plates.

This work, another recent contribution to the areal geology of hitherto little-known regions, is a valuable reference on Trinidad. The island, integrally a part of the South American continent, is more than 1,800 square miles in area. The structural and physiographic trend or grain is uniformly east-west, with alternating belts of lowlands and highlands, the latter rising locally to elevations of more than 3,000 feet.

The oldest members of the stratigraphic column are pre-Cretaceous (early Mesozoic?) schists and limestone, with a local granophyric intrusion. These are followed by Cretaceous shales and sandstones, overlain in turn by a full Tertiary succession of shales, clays, and sands, with local coal seams. Quaternary deposits are confined to alluvial and swamp materials.

The northern portion of the island, composed of the oldest rocks, is structurally related to the Parian Peninsula of Venezuela on the west, and also to the island of Tobago on the northeast. This section is intensely folded and faulted. Deformation of a less pronounced character is evidenced throughout the greater part of Trinidad.

Several producing oil fields are scattered throughout the southern part of the island, their output fluctuating considerably. In 1924 the total production was 4,284,000 barrels, from the properties of sixteen different companies. The oil is thought to originate in thick Miocene foraminiferal marls and clays. Asphalt and "manjak" (a bitumen related to gilsonite) have been quarried extensively in the past, the former being used for pavement and the latter in the preparation of paints. The coals in the Tertiary succession are of lignitic grade, and are valuable only for local uses.

RICHARD FOSTER FLINT.

Deposits of Brown Iron Ores in Western North Carolina. By W. S. BAYLEY. Bull. 31, No. Carolina Geol. and Econ. Surv. 76 pages, Raleigh, N. C., 1925.

This bulletin combines in a concise form a description of the many localities in which brown hematite deposits occur in western North Carolina with a discussion of the geology of the ores of each district and of the probable ore reserves in the neighborhood of the workable deposits.

The author states that the ores are all hydrated iron oxides, mostly limonite and goethite, though some may be composed largely of other compounds, occurring in veins and residual deposits. The veins were

formed after the deformation of the enclosing rocks and are due to downward percolating waters. The residual deposits are found in the residual soil mantle or in the partly decomposed rock below.

The greater part of the bulletin is devoted to the description of the ores in the valley between the mountains of Madison and Cherokee Counties that include most of the developed properties. A final section considers the deposits of the Piedmont Plateau where the ores are rather widely distributed as small deposits of doubtful value.

This bulletin will serve to direct attention to those regions where the ores are most likely to prove profitable and will be of practical importance to all who are interested in the development of the iron industry in the state.

W. M. AGAR.

The Kaolins of North Carolina. By W. S. BAYLEY. Bull. 29, No. Carolina Geol. and Econ. Surv. 132 pages, Raleigh, N. C., 1925.

This bulletin is devoted to a discussion of the high-grade clays or kaolins that occur widely distributed to the west of the "fall line" in the Piedmont Plateau and Appalachian Mountain districts of North Carolina. These are all residual deposits and therefore differ in origin and use from the transported clays that lie to the east of the fall line.

The bulletin discusses the origin of kaolin, the kaolinization processes, the preparation of kaolin and by-products, prospecting and the uses of North Carolina kaolins, and describes in detail the occurrences of kaolin in the mountain belt. These are residual products formed by the decomposition of abundant pegmatite dikes. They are the more important of the two groups and the more thoroughly developed commercially.

A shorter section is devoted to the kaolins in the Piedmont Plateau. These are not yet commercially developed and differ from those of the mountain belt in that they are formed by the alteration of granites, schistose felspathic rocks, and slates, as well as pegmatites, but, with the exception of the slate derivatives, they are believed to be of some importance.

The total amount of kaolin in North Carolina is stated to be great but most of the deposits are too small to be profitably worked at present. The fact that the discovery of a few workable deposits has encouraged the search for others nearby is thought to explain the concentration of the known deposits about a few centers in spite of the widespread distribution of the pegmatites. With better roads in the future and consequent easier access to the mountain districts it is believed that sufficient deposits may be found to prolong the existence of the kaolin industry beyond the thirty-nine years indicated by the present known reserve.

W. M. AGAR.

SCIENTIFIC NOTES AND NEWS

William Otis Hotchkiss has been inaugurated as president of the Michigan College of Mines at Houghton, Mich.

E. F. Bean is state geologist of Wisconsin, having succeeded W. O. Hotchkiss, resigned.

Alan M. Bateman has returned from Europe, having left in April to attend the International Geologic Congress at Madrid.

Gail F. Moulton, of the Illinois Geological Survey, has been studying the oil fields at Centralia.

J. Volney Lewis, of Rutgers University, has been in California for some weeks on professional business.

James Chamberlain, mining engineer with the Butte and Superior Mining Company, has taken up work for a mining company in Bolivia.

Marshall D. Draper, mining engineer of Los Angeles, has gone to China, and will have headquarters at Kotchiu Yunnan.

Thomas N. Miller, of Tientsin, has been making an extensive exploration in Inner Mongolia for the Chung Wha Mines Company.

R. S. Botsford, mining engineer, has been appointed director of the Zancudo mine in Colombia.

Adolph Knopf, of the department of geology, Yale University, is in Pioche, Nevada, investigating the geology of the district for the U. S. Geological Survey.

J. D. Mertie, Jr., of the U. S. Geological Survey, and his party have returned to Yukon, Alaska, after mapping an area of 1,200 square miles in the upper Salmon River valley.

A. McIntosh Reid, chief government geologist of Australia, has been appointed by the Tasmanian Government as director of mines of Western Australia, in pursuance of a new mining policy recently adopted.

Louis Reber, who has been chief geologist for the United Verde Copper Company at Jerome, Arizona, has taken a position with an English mining syndicate in Rhodesia.

Henry Mace Payne, consulting engineer for the American Mining Congress, is now also consulting engineer and geologist for the Gulf, Mobile and Northern Railroad, and has closed his office in New York City.

J. E. Eaton has resumed general consulting work, with offices in Los Angeles, after nearly two years of geological mapping in California for the Milham Exploration Company.

Russell C. McGinnis, formerly with the Copper Queen Branch, Phelps Dodge Corporation, is now connected with the U. S. Income Tax Unit as valuation engineer.

Clarence A. Fredell, formerly with the A. S. and R. Company at Agangueo, Michoacan, Mexico, is now chief engineer for Neg. Minera San Rafael y Anexas, Magdalena, Jalisco, Mexico.

K. Lundberg, geologist and electrical engineer of Sweden, has recently visited the Rouyn gold area of Quebec with a view to introducing an electro-magnetic system for locating copper orebodies under a heavy overburden.

W. J. Mead, of the department of geology of the University of Wisconsin, is on leave of absence for the coming college year, and will give courses in metamorphic and structural geology at the University of California, Berkeley.

A. B. Combe has recently been making a trip from Uganda to the Cape of Good Hope via the northwestern Tanganyika Territory, southeastern Belgian Congo, Rhodesia and the Transvaal in order to compare the ancient fossiliferous sedimentary rocks of eastern Central Africa with those of the Union of South Africa.

Willis T. Lee, of the U. S. Geological Survey, died on June 16th. He was born in 1864 and educated at Wesleyan and Chicago Universities and Johns Hopkins. He was a lecturer and writer, and a member of many scientific societies.

W. L. Uglow, professor of mineralogy and petrography at the University of British Columbia, died at Vancouver on August 3d as a consequence of injuries received while diving at Honolulu. He was returning from Hongkong, where he had been engaged in geological work for the Hongkong Government.

The American Association of Petroleum Geologists have announced their permanent headquarters in the Public Library Building, Tulsa, Okla. J. P. D. Hull has resigned as chief geologist of the Louisiana Oil Producing Company at Shreveport, to become business manager of the Association.